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THE HOST MINERALS OF NATIVE GOLD.

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ABSTRACT.

An intensive review of the literature as well as microscopic study of many ores shows that gold occurs most frequently in direct contact with the following ore minerals in the order named: pyrite, arsenopyrite, galena, sphalerite, chalcopyrite, bismuth minerals, pyrrhotite, tetrahedrite-tennantite. The most common gangue minerals containing gold are: quartz, carbonates, chlorite, graphite (including other carbonaceous material), and tourmaline. Many other minerals are occasional hosts for gold. Available data suggest that few minerals are effective precipitants of gold under natural conditions although the possibility of precipitation of gold by the host mineral is not denied. Variability in the relation of gold to host minerals is common and it is concluded that each occurrence must be studied separately in deciding which mineral or minerals are valuable guides to gold values.

INTRODUCTION.

THE most important attempt to discover the exact relation of gold to minerals in general is Lincoln's review, published in 1911.[66] Inasmuch as this work was published before the microscopic study of polished ores was well developed, it should now be possible to gain a much more accurate idea of the relation of gold to associated minerals. The writer has studied polished surfaces of gold ores for some time but only recently has time permitted an adequate review of the literature. Because Lincoln's paper covers early data so well, the writer has largely, though not entirely, confined his study to papers published since 1911.

The method of attack is somewhat different from Lincoln's. Special emphasis has been placed on examples where gold was

seen, or otherwise proven, to be directly in or with the various minerals. It certainly would not be correct to say that the minerals in a vein which are not known to contain gold have no significance, but the significance is limited as compared with minerals in direct contact. The associated minerals show what elements were present in the mineralizing solutions and some of them give us an insight into conditions of deposition. It seems evident, nevertheless, that the minerals which may have played a part in precipitating the gold, and therefore in localizing it, must be the minerals with which the gold has direct contact.

In the present review 115 deposits yielded more or less definite data on the occurrence of native gold. These include most of the large deposits, except placers. Literature on a great many other deposits was examined but definite statements on the relation of the gold were lacking. In this connection it must be remembered that many gold deposits show little or no native gold visible to the naked eye. Very careful studies of highly polished ores are ordinarily necessary to reveal the relation of gold to specific minerals and even then the data are probably often incomplete.

It was considered best to discuss each mineral separately, giving especially a summary of significant occurrences described in the literature. These were checked by laboratory examination of extensive material in the collection at the University of Minnesota. General features are then discussed on the basis of the evidence presented. Ore minerals are discussed first, gangue later. The arrangement in each is alphabetical.

The writer is indebted to many individuals and companies who have at various times contributed gold ores to the University of Minnesota collection. Special thanks are due to Frank F. Grout for suggestions and critical reading of the manuscript.

THE MINERALS WITH WHICH GOLD IS DIRECTLY ASSOCIATED.

Ore Minerals.

Argentite: Argentite is an important mineral in many epithermal gold-silver deposits, but direct association of argentite and

native gold does not seem to be common; however, a few examples have been briefly referred to in the literature. Rickard [65] observed that silver sulphide and gold were associated in the Enterprise Mine, Rico, Colorado, but no details of the occurrence were given.

Bastin [4] found gold in argentite adjacent to sphalerite and galena in ore from the Comstock Lode. In the Waihi district of New Zealand argentite is an important mineral in the silver-gold ores but, unfortunately, details of the relation to gold are lacking, although it is fairly evident that the two are closely associated. Lincoln [66] reported 39 of the gold veins tabulated contained argentite, of which seven appear to represent direct contacts. The descriptions published since 1911 are so lacking in descriptions of native gold with argentite that the opinion seems warranted that the association is not important in the principal gold deposits. It may be remarked in this connection that argentite would be expected to occur mainly in the epithermal deposits which furnish only a moderate number of gold deposits, but some of the richest ore.

Arsenopyrite: The association of gold with arsenopyrite in many districts has long been recognized. In some deposits, the association is direct, that is, the gold occurs in or on the arsenopyrite. In a few deposits arsenopyrite is present but seems to have little connection with the distribution of the gold. Barren arsenopyrite is not unusual in some deposits where gold definitely occurs in part of the arsenopyrite. The questions raised by the study of the relation of gold and arsenopyrite are similar to those raised in regard to pyrite.

Out of 115 districts reviewed, 45 have native gold described as directly related to arsenopyrite. In several of the remaining districts arsenopyrite is present in the ore but no direct relation was described.

A review of all of the details of the occurrence of gold in arsenopyrite is not practicable, but some of the more significant comments found in the literature may be summarized. The Homestake Mine furnished a particularly important example of

abundant arsenopyrite in a gold ore. Sharwood [92] long ago called attention to the considerable amount of gold in arsenopyrite. Visible gold is often found on microscopic examination and assays show a preference of gold for arsenopyrite although gold also occurs in quartz, chlorite, and pyrrhotite. The writer is indebted to Dr. James A. Noble for the results of years of work in the mine and laboratory. Noble's results in general agree with those of Sharwood. Pyrrhotite inclusions in arsenopyrite are often partly replaced by gold. Gold also occurs in pyrite and galena, and rarely, in magnetite. In some of the outlying parts of the mine there is no close relation between gold and arsenopyrite.

In the Morro Velho [29] deposits of Brazil arsenopyrite is also the principal host mineral. High arsenical ore is rich in gold.

There are numerous gold deposits in British Columbia and several have furnished valuable data on the mineral associations of native gold. In the Bridge River district Cairnes [14] found free gold common with acicular crystals of arsenopyrite. In some rich bodies the arsenopyrite was minutely veined and replaced by gold. Dolmage [22] noted in the same district that gold veinlets are more abundant and persistent in arsenopyrite than in other minerals. Smitheringale [95] reports that a study of assays of ore from the George Gold-Copper Mine of Stewart, British Columbia, shows that gold is associated with arsenopyrite inasmuch as the gold content of the ore varies directly with the arsenopyrite content. An interesting photograph of gold replacing arsenopyrite pseudomorphically is shown by Stevenson [96] in ore from the Zeballos district, also in British Columbia. Sharpstone [91] states that in the Polaris-Taku Mine gold values are uniform and have a direct relationship to the amount of arsenopyrite in the ore. In some areas of the mine arsenopyrite carries more gold than in others, but is nowhere barren, and good arsenopyrite mineralization indicates good values.

In the Alleghany district [27] of California free gold occurs mainly with arsenopyrite and has replaced it along fractures. Arsenopyrite is an important constituent of some of the gold ores of southwestern Oregon, according to Lowell.[68] Free gold occurs intimately with arsenopyrite in some mines. Lines of tiny gold

blebs occur parallel to fronds of fern-like forms of arsenopyrite in the Warner prospect and gold fills cavities in skeletal crystals.

Gunning [36, 37] found arsenopyrite to be the most distinctive metallic mineral of all the commercially attractive gold deposits of the Cadillac area of Quebec. In the Beattie Mine, Quebec, gold occurs with fine arsenopyrite and arsenic is abundant enough in the ore to create a problem of disposal.

In Northern Sweden, at Boliden [78] and Skellefte,[79] are gold-bearing deposits in which arsenopyrite is important. Ödman notes that gold is closely associated with arsenopyrite and much gold occurs directly in that mineral. The gold is later than arsenopyrite and Ödman believes it to have formed at Skellefte by some process of replacement or molecular migration.

Thomson [103] states that in the Manitou-Lake of the Woods area the gold content of the ore is roughly proportional to the arsenopyrite content.

In polished surfaces of gold ores studied by the writer several excellent examples of gold with arsenopyrite were observed. A particularly rich specimen from the Tightner Mine, Alleghany district, California, consists of much fractured arsenopyrite in which gold is visible to the naked eye. Polished surfaces show that the fractured arsenopyrite is cemented mainly by quartz with irregular inclusions and stringers of gold in the arsenopyrite (Fig. 1). The gold is probably a replacement of arsenopyrite but the distribution of gold is extremely irregular and even the veinlet of gold in figure one ends abruptly in arsenopyrite. A somewhat similar occurrence was found in arsenopyrite from the property of Tionago Gold Mines, Ltd., Horwood Lake, Ontario. The gold occurs in cracks in arsenopyrite (Fig. 2).

In ore from the Darwin (Grace) Mine of the Michipicoten district arsenopyrite is not an abundant constituent but the manner in which gold nearly surrounds arsenopyrite in one specimen is suggestive of a possible chemical relation (Fig. 3). In another specimen arsenopyrite may have been slightly replaced by gold (Fig. 4).

Other districts or mines in which direct relations of gold and

arsenopyrite are described in the literature include: Flin Flon, Manitoba, Northwestern Quebec; Casummit Lake, Red Lake, and Little Long Lac in Ontario; Victoria, Australia; Salsigne, France; and many others.

The data suggest that arsenopyrite may be fairly effective though not always a consistent precipitant of gold. It is im-

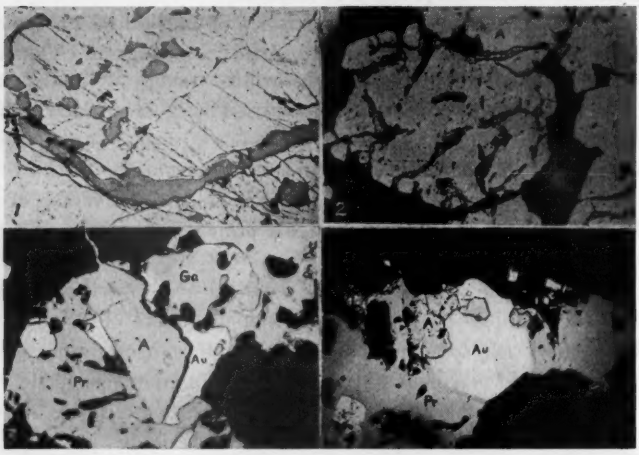

FIG. 1. Gold veinlet and irregular inclusions in arsenopyrite. Tightner Mine, Alleghany district, California. ×22.

FIG. 2. Gold (medium gray) in fractures in arsenopyrite (A) with quartz (black) matrix for fragments of arsenopyrite (A). Horwood Lake, Ontario. ×165.

FIG. 3. Arsenopyrite crystal (A) with gold (Au) in pyrrhotite (Pr) and galena (Ga). Darwin Mine, Michipicoten district, Ontario. ×83.

FIG. 4. Gold (Au) area in quartz (black) and pyrrhotite (Pr). Arsenopyrite (A) grains and crystals in gold and pyrrhotite. Darwin Mine, Michipicoten district, Ontario. ×110.

portant to note, however, that microscopic relations of gold to arsenopyrite are not as diagrammatic as would be expected if replacement were really selective. In that case rims of gold around small grains, continuously filled fractures, and other re-

lations should appear. Possibly the importance of arsenopyrite as a host may be a matter of association rather than actual precipitation by the host.

Bismuth Bearing Minerals: Native bismuth, bismuthinite, galenobismutite, cosalite, and probably other bismuth minerals occur in a few gold ores. Descriptions in the literature usually emphasize the importance of these minerals when present and the conclusion, especially in the case of galenobismutite, seems to be warranted that these minerals act as a precipitant of gold.

At Goldfield, Nevada,[84] gold occurs in bismuthinite as well as in several other minerals. Tolman and Ambrose[106] believed the tellurides to have been precipitated by bismuthinite.

Galenobismutite is relatively abundant in ores from the Boise Basin, according to Ross,[87] and primary intergrowths of gold and bismuth occur also. According to Hutl[53] native gold and lead-bismuth sulphides are intimately associated in a late mineralization along fractures in quartz. Bismuth is believed to indicate good values in the Boise district. Skidmore[94] identified galenobismutite and tetradymite in ores of the Talache Mine of Idaho and noted that the presence of bismuth usually indicated good values.

Stillwell and Edwards[99] have reported examples of gold in native bismuth from Cobar and from Tennant Creek in Australia.

Bismuth and bismuthinite appear to be related to the localization of gold in the Windpass Mine, British Columbia, and Warren[109] has emphasized the importance of bismuthinite and cosalite in the Cariboo Gold-Quartz Mine of the same province. Gold is readily visible to the naked eye in many samples but is most prominent in galenobismutite and cosalite. At places gold is reported to amount to as much as 10 per cent of the mineral by weight. Cosalite is veined by gold which also occurs as scattered "nuggets." In the Waneta property[110] of British Columbia a lead-bismuth mineral, probably galenobismutite, and gold telluride are closely associated.

Lowell[68] has described gold ores from southwestern Oregon which carry significant amounts of native bismuth and tetra-

dymite. The Irwin and Jewett mines are mentioned particularly. An intimate intergrowth of tetradymite, native tellurium, altaite, and gold occurs in the ore of the Jewett and Caster mines. Gold-quartz veins cut tetradymite and gold occurs intimately intergrown along the twinning directions of tetradymite.

In ores of the Howey Mine, Red Lake, Ontario, bismuth minerals are important according to Mather.[69] Tetradymite, sylvanite, and altaite commonly contain free gold. Galenobismutite is intergrown with tetradymite, aikinite, chalcopyrite, and free gold. In gold telluride ores of the Manitou Lake-Lake of the Woods [108] area gold occurs largely with tetradymite.

If bismuth minerals were more widespread in occurrence, it may be surmised that they would be of very great importance in the localization of the gold.

Boulangerite: Junner [58] reported boulangerite among the favorable minerals in the precipitation of gold at Daylesford, Australia. Gold also occurs occasionally as rounded grains included in boulangerite from the Skellefte district, Sweden.[79] Ridland [86] found gold in direct association with boulangerite in the complex ores of the Yellowknife district.

Boulangerite is a relatively uncommon mineral and would not be expected to play an important role as a host for gold, although it may do so in the rare deposit where it is abundant.

Bournonite: Bournonite probably has about the same significance as boulangerite in the occurrence of gold. At the Little Long Lac Mine, Ontario, Bruce and Samuel [12] report tiny rounded grains of gold in bournonite. Junner [58] includes the bournonite as a favorable mineral at Walhalla-Wood's Point, Australia. An example is shown in Plate II of Junner's paper.

Chalcocite: Native silver is well known with chalcocite, often being deposited on the fracture surfaces. Palmer and Bastin [80] showed experimentally that both silver and gold were precipitated on chalcocite, which was considered especially effective as a precipitant. In nature, however, chalcocite seems to be of slight importance in precipitating gold. Possibly this is due to the relatively low gold content of many copper ores. Some large

gold bearing copper deposits, for example the Horne Mine, contain little or no chalcocite. Aside from the occurrence reported by Sales [113] from the 1,000 level of the Leonard Mine at Butte, the writer has found no example of gold on chalcocite. However, Lincoln [66] reported eight districts as having explicit examples of gold and chalcocite associated, of which five appear to represent direct associations.

In the formation of supergene chalcocite gold would not ordinarily be carried by the same solutions. In epithermal deposits there does not seem to be any special reason why they should not have been deposited together, but they have not been insofar as the writer can determine.

Chalcopyrite: Gold ores frequently contain small amounts of chalcopyrite and direct contact between the two is not unusual. In a few ores chalcopyrite is an indication of good values. The Horne Mine and Flin Flon furnish large scale occurrences of gold-chalcopyrite ores but in these chalcopyrite can scarcely be considered an indication of gold values which are subordinate to those of copper.

Some examples of gold ores with small amounts of chalcopyrite but closely associated with the gold may be noted. Hulin [50] has observed that in the Mother Lode ores appreciable areas of gold rarely occur without blebs of chalcopyrite. In southwestern Oregon [68] gold occurs included in chalcopyrite near the outer edge of grains, also as veinlets cutting chalcopyrite. In the Red Lake-Gold Shore Mine of Ontario, Mawdsley [70] noted that chalcopyrite veinlets in pyrite commonly carry gold. In the Harvey Mine [69] of the same area chalcopyrite is considered indicative of high gold values. In the Bridge River area [14] of British Columbia gold is closely associated with chalcopyrite as well as with several other minerals. In the Iron King Mine, Arizona, Mills [72] stated that chalcopyrite was one of the best hosts for gold. Odman says that in the Skellefte district of Sweden a large part of the gold occurs in chalcopyrite, which veins and replaces arsenopyrite. Ridland [86] found a few specimens in the Yellowknife district which contained gold and chalcopyrite in irregular contact with one another.

In several rich gold specimens of sulphide ores examined by the writer on polished surface chalcopyrite was found closely associated with gold. Gold was found in contact with chalcopyrite in ore from the Carson Hill Gold Mine, California. A somewhat similar relation (Fig. 5) was found in ore from the Darwin Mine, Michipicoten district.

Chalcopyrite and tellurides were found associated with gold along cracks and grain boundaries of quartz from Kirkland Lake, Ontario. Sphalerite from the Hollinger Mine contains inclusions of gold, chalcopyrite, and pyrrhotite. In none of these occurrences, however, would the relations suggest that chalcopyrite acted as a precipitant of the gold.

Tabulation of the results of the review involved in this paper shows that in 23 out of 115 districts, chalcopyrite and gold are directly associated. Chalcopyrite is present in many other deposits but no statement of direct relations was found. It may be assumed, however, that gold does occur in chalcopyrite in some of these districts as it would escape detection except by very careful observation because of the similar color of the two minerals.

Cobaltite: A rich shoot of cobaltite with high gold values has been described by Uglow and Osborne.[107] The cobaltite, however, was not much replaced but possibly acted to precipitate the gold in other minerals, especially magnetite according to the authors.

Pelletier[82] notes that highly auriferous cobaltite has been reported from the East Rand area in Africa. Cobaltite is not of much significance in the ore as a whole.

Famatinite: Ransome[84] reported gold and famatinite intimately intergrown in rich ores from Goldfield, Nevada, and considered them contemporaneous, but Tolman and Ambrose[106] observed veinlets of gold cutting famatinite. The relation of gold and famatinite seems an important one at Goldfield, but the rarity of famatinite probably is sufficient explanation of the unimportance of this association in gold ores of other areas.

Galena: There are numerous references to gold occurring in or on galena in gold deposits. Commonly the galena is not an abun-

dant mineral but formed at a late stage, often at about the time of introduction of the gold, and thus may be a good indicator of gold values. Cockfield,[17] for example, found the high gold content of some ores from the Ymir-Nelson area was commonly, but not always, associated with high galena and probably, also high sphalerite. Dougherty [23] noted that galena and sphalerite are of high gold content in some quartz bodies of Canadian pre-Cambrian gold mines. Hurst [51] specifically noted that in the Red Lake deposits galena and sphalerite indicated higher than average gold values. In the Cariboo-Bridge River area [22] of British Columbia galena is a common accompaniment of gold in veinlets. In the Lupa Goldfield, Africa, according to Gallagher,[30] galena rich specimens containing other sulphides are extremely rich in gold. In the Camp Bird vein of Ouray, Colorado,[78] gold and hessite occur in galena. At Telluride Hurst [51] reported gold replacing galena and polybasite. Gold in fractured galena occurs in the Mother Lode gold ores.[50] Galena is also a common host for small blebs of gold in the Hollinger ore. At Grass Valley, California,[61] gold, galena, and sphalerite were deposited in intimate contemporaneous association by late solutions which penetrated fractures in quartz and pyrite.

In discussing the gold mineralization of Nova Scotia Newhouse [75] says, "In this region, as in some others, gold is associated with the relatively late mineral, galena, to a sufficient extent so that the lead sulphide is regarded as a good indication of high gold values."

At the San Mauricio Mine [2] in the Philippine Islands gold is found in intimate association with galena and sphalerite. In the Flin Flon Mine [10] specimens containing abundant arsenopyrite have gold and galena replacing the arsenopyrite along fractures or grain boundaries. In Idaho County, Idaho,[67] galena is an indication of comparatively high gold values and is abundant in many of the higher grade veins. In some of the mines of southwest Oregon [68] gold occurs in galena. Steel galena contains gold streamers due to granulation and recrystallization of gold during rock flowage. Gold also occurs as rounded grains in galena, with

which it is considered contemporaneous. Gold veinlets also cut galena. In the Battle Branch Gold Mine [81] of Georgia the final mineralization is a chlorite-gold stage with no age difference between galena and gold. These minerals occur in fractures and irregular patches through the other minerals.

The examples cited are the more important of those noted. In 30 out of 115 districts, gold and galena have been found in contact. Galena is a common minor constituent of many other gold ores, but a direct association was not described.

In specimens studied by the writer, gold and galena were found in direct association in ores from the Michipicoten district, Ontario, and the Allegheny district, California. Gold and galena appear to be contemporaneous in a specimen from the Deep Lake Mine, Michipicoten, where they cut sphalerite (Fig. 6). In ore from the Darwin Mine gold also occurs in contact with galena.

In a rich specimen of arsenopyrite from the Tightner Mine, referred to under arsenopyrite, one irregular inclusion consists of gold and galena.

In an extremely rich telluride-gold specimen from the Carson Hill Mine, California, galena is abundant, but in the polished surfaces native gold does not occur in contact with galena although telluride (petzite) occurs as inclusions and also at the contact of galena.

In many gold deposits galena is a late mineral and since gold is usually the last mineral in the paragenetic series the two occur together, not only because of the precipitating power which galena may have, but, also, because of the purely mechanical association of minerals forming at about the same time and place. Hulin [50] has emphasized this factor and also believes galena to be a particularly favorable host for gold because of the ease of fracturing due to good cleavage. It should also be noted that Palmer and Bastin [80] determined experimentally that galena is an active precipitant of gold from chloride solutions.

Gersdorffite: Krieger [64] described native gold in fractures in gersdorffite but this is the only occurrence which the writer found in the literature.

Gudmundite (*FeSbS*): This rare mineral is reported [86] in some of the veins of the Yellowknife district, where it contains minute grains of gold.

Jamesonite: Although jamesonite is reported in a number of gold veins, direct relations between the gold and jamesonite seem rare. Ridland [86] described jamesonite projecting into gold in a specimen from the Yellowknife district and in another specimen noted that the gold boundaries appear to be controlled by jamesonite cleavage. Lincoln reported two occurrences of gold disseminated in jamesonite and two of gold with jamesonite.

Magnetite: Gold is not commonly found in magnetite although the mineral occurs in some gold deposits. In the Windpass Mine of British Columbia free gold is abundant in magnetite, according to Uglow and Osborne.[107]

In the Ajax Mine, Willow Creek, New Mexico, magnetite has extensively replaced a carbonate rock with low values in gold associated with the magnetite. There are doubtless other occurrences, but they have not been observed or described in detail in the papers reviewed. Lincoln found records of gold more or less closely related to magnetite in seven districts out of 585 occurrences of gold in veins.

The writer is indebted to James F. Noble for the statement that gold has replaced magnetite in a few specimens from the Homestake Mine.

Millerite: Krieger and Hagner [64] have reported primary millerite containing gold in small amounts at Alistos, Mexico. Inasmuch as millerite is a rare mineral in gold deposits, it could scarcely be of much significance. However, Palmer and Bastin [80] showed that millerite precipitated gold when suspended in gold chloride so that within four minutes most parts of the specimen were coated. Obviously, ability to precipitate gold is only one of several factors involved in the importance of various minerals in gold deposits.

Molybdenite: Small amounts of molybdenite are common in hypothermal deposits. It does not, however, appear to have much importance in the occurrence of gold, although its intimate asso-

ciation with native gold has been noted in the San Mauricio Mine [2] of the Philippine Islands. Wilkinson, in 1867, and Skey, in 1871, are reported by Palmer and Bastin [80] to have precipitated gold on molybdenite in experiments with gold chloride. It seems, however, that if molybdenite were a really effective precipitant, its direct association with gold would have been reported more often. Lincoln [66] reported only one example of gold intergrown with molybdenite.

Niccolite: Krieger and Hagner [64] reported abundant native gold in niccolite and to a lesser extent in other nickel minerals from Alistos, Mexico. The gold occurs between grain boundaries of the niccolite and replaces the minerals as well. Niccolite was found by Palmer and Bastin [80] to be a rapid and effective precipitant of gold from gold chloride solutions. The mineral, however, is so rare in gold deposits that its ability to precipitate gold has significance only in an exceptional deposit.

Polybasite: Brokaw [9] used polybasite as an example of complex sulpho-salts in experiments on the precipitation of gold from gold chloride solution. After a crystal was in the solution for ten days, gold was completely precipitated from a 0.5 per cent solution of gold chloride.

Polybasite is an abundant mineral in very few deposits and where it does occur in rich silver ores, it is very often as microscopic grains and inclusions with other minerals, especially tetrahedrite. It is evident that only the most careful studies would reveal the association of polybasite and gold. Hurst [51] reports such an example from Telluride, Colorado, where native gold replaced polybasite. Mather [69] found polybasite as inclusions in galena commonly contained blebs of free gold in ores from the Howey Mine, Red Lake, Ontario.

Pyrargyrite: Lincoln [66] reported four examples of a close association of gold and pyrargyrite but no details are available. In the recent literature the writer failed to find an example of direct association described; however, in a specimen from the Van Roi Mine, British Columbia, in the University of Minnesota Mineralographic Collection gold occurs as an area and veinlets in pyrargyrite (Fig. 7).

Pyrite: There has been much speculation and investigation as to the mode of occurrence of gold in pyrite. Only in recent years has the technique of polishing and microscopic examination advanced to the point where dependable information could be obtained. Head, Horwood, Graton, and others have contributed modern data. Graton and McKinstry's [35] description of the relation of gold to pyrite in the Hollinger veins summarizes the modern viewpoint. A large proportion of the gold values in the ore is in intimate association with pyrite. Gold fills fractures in pyrite or occurs along crystal faces or as rounded blebs within pyrite grains. Some is contemporaneous with pyrite, some is later. There is no evidence of chemical combination or solid solution with pyrite and there is always sufficient gold visible under the microscope to account for the assay values.

The writer found gold described as in contact with pyrite in 48 out of 115 deposits reviewed. In view of the fine technique required to polish pyrite so as to preserve the associated gold so that it may become visible, it may be safely assumed that pyrite in many of the remaining deposits actually contained some gold.

Pyrite and gold are so closely associated in many gold deposits that their close relationship is almost taken for granted. It is, however, surprising, on studying the literature of the gold deposits, to find many exceptions. Since the association of gold and pyrite is well known, the numerous examples will not be reviewed, but attention will be called to unusual examples and exceptions.

In the Spring Hill gold deposit [57] near Helena, Montana, pyrite carries possibly the bulk of the gold, but some pyritic rocks are barren. Cooke found in ores of the Larder Lake district,[18] Ontario, no connection between the concentration of pyrite and the gold content of the rocks. In the Patricia Gold Mine Cormie [19] states that gold seems to be associated with all of the sulphides except pyrite. At the Canadian Malarctic Mine [37] high pyrite content usually indicates good values but cores have been found where pyrite assayed only a trace of gold. Dolmage [22] noted in the Cariboo district that gold veinlets in quartz died out quickly on entering pyrite. Cleveland [16] described an example

from the Premier Mine where bunches of arsenopyrite are associated with high gold values but similar bunches of pyrite do not give high values. Also in the Whitewater district of British Columbia gold is found in arsenopyrite in preference to pyrite. In the Cadillac area of Quebec Gunning [36] states that massive pyrite and pyrrhotite are commonly barren or low grade. However, some gold does occur in pyrite and against pyrrhotite. In the Argosy Mine Horwood [47] noted that when pyrite alone is present the values are poor. Skidmore [94] states that in the Gold Hill Mine pyrite crystals are sparsely disseminated through the altered rock and in the fractures but are not an important locus of gold. At Meckatharra Emmons [25] states that the gold is not concentrated in the pyrite and pyrite is regarded as a "bad indication."

Head [43] has made extensive studies of the occurrence of gold in pyrite. His conclusion is that all gold in low grade pyrite ores is on the crystallographic faces of the pyrite. The writer's review of many occurrences suggests that in high grade specimens the pyrite is commonly fractured and gold occurs in the fractures, although it may also occur as isolated inclusions in the pyrite.

Bruce and Samuel [12] report that gold of the Little Long Lac ores occurs as thin plates along the faces of pyrite and arsenopyrite crystals, and as blebs within crystals that show no fractures. Also Gallagher [30] notes that in the Lupa goldfield of Tanganyika gold occurs as fillings in pyrite, droplet-like enclosures in pyrite, and as irregular grains tangential to pyrite.

The situation for pyrite may be summed up briefly by saying that, whereas much gold does occur with pyrite, its association is not universal nor consistent. In some deposits pyrite is essentially barren, in others some of the pyrite carries values and some is barren. The almost universal distribution of pyrite in ores probably accounts for the common association rather than any special precipitating power which pyrite might have.

In specimens studied by the writer gold was frequently noted as inclusions in pyrite or in contact with the pyrite boundaries. In most specimens, however, there is no particular evidence of pyrite

acting as a selective precipitant of gold. For example, in ore from Kirkland Lake, the pyrite grains seem merely a sporadic occurrence in the native gold. In Figure 8 the gold seems to have replaced the pyrite, although it is not a continuous veinlet across the specimen. In many specimens from the Michipicoten district pyrite is present, and at places in contact with, gold, but the relation seems accidental.

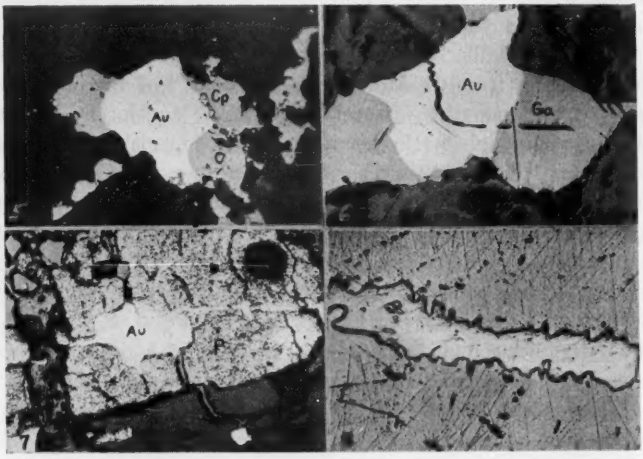

FIG. 5. Gold (Au) and chalcopyrite (Cp) in quartz. Darwin Mine. × 138.

FIG. 6. Gold (Au) and galena (Ga) in sphalerite. Deep Lake Mine, Michipicoten district, Ontario. × 83.

FIG. 7. Gold (Au) area and veinlet probably replacing pyrargyrite (P) with quartz (Qz). Van Roi Mine, British Columbia. × 83.

FIG. 8. Gold stringer which has replaced pyrite. Unknown Canadian gold mine. × 83.

Pyrrhotite: In hypothermal deposits pyrrhotite is commonly important. In some gold-bearing hypothermal veins pyrrhotite seems to have played an important role in localizing the gold but in other deposits pyrrhotite is essentially barren. The erratic occurrence of gold with pyrrhotite has been noted by Dougherty [23]

in his review of Canadian deposits. Palmer and Bastin's experiments indicated little difference in the precipitating power of pyrite and pyrrhotite when immersed in gold chloride solutions.

In specimens of gold ores studied by the writer gold has been observed in pyrrhotite from the Michipicoten district and the Homestake Mine of South Dakota. In the Homestake ores Sharwood long ago described gold with pyrrhotite and noted that a little pyrrhotite occurred near or in contact with gold in other minerals, notably arsenopyrite.

Somewhat similar relations to those in the Homestake ores are found in ores from the Morro Velho deposits [29] of Brazil. Gold occurs in arsenopyrite adjacent to pyrrhotite and locally in pyrrhotite. The high pyrrhotite ore, however, is usually low grade.

Pelletier [82] has recently reported detailed microscopic studies of the Rand ores and finds a marked association between gold and pyrrhotite. Pyrrhotite concentrates show higher assays (about double) than pyrite, which is much more abundant in the ores. Under the microscope gold also appears much more commonly in pyrrhotite than in pyrite. Pettletier's Figures 7, 8, 9, and 11 show irregular rounded inclusions of gold in pyrrhotite with some crystal face boundaries visible on some inclusions.

Through the courtesy of Dr. M. H. Frohberg the writer has an excellent collection from the Michipicoten district which contains many specimens of pyrrhotite ore carrying native gold. The relation of the gold to pyrrhotite is variable. Gold occurs as irregular inclusions (Fig. 4) in pyrrhotite, irregularly distributed as veinlets, and as areas along contacts of other minerals in pyrrhotite (Fig. 3). In one specimen gold is abundant along a crack in quartz but little occurs along the same crack where it cuts pyrrhotite. In this suite there is so much gold in pyrrhotite that one may well conclude that pyrrhotite is a good host, but there is an absence of textural relations which would suggest any special precipitating effect.

Scheelite: Scheelite is a minor constituent of some hypothermal deposits, particularly in Canada. Only rarely, however, is gold found directly with the scheelite. Minor amounts of gold are

found as inclusions in scheelite and also along fractures in scheelite, as occurs in the ore of the Hollinger Mine. No other examples were found described in the literature but doubtless gold may occasionally occur in scheelite of other mines where it is a common constituent—for example, the Siscoe Mine of Northwestern Quebec.

Specularite: A few examples of the association of gold with specularite have been described. This occurrence does not seem significant except as an indication of fairly high temperature of formation at an early stage in formation of the veins.

Burbank [11] and Moehlemann [78] have reported gold with quartz and specularite, and gold was seen in actual contact with specularite in the Ouray district of Colorado. In other deposits where specularite is reported descriptions of the relation to gold were not stated.

Sphalerite: Some occurrences of gold in sphalerite have been noted in the discussion of galena. In general the occurrences in sphalerite are not quite as numerous and the genetic relation is, perhaps, not as evident in many cases. There are also somewhat erratic features in the case of sphalerite. For example, Cleveland [16] noted in the Bralorne and Pioneer Mines that brown sphalerite was invariably associated with higher gold values, but, on the other hand, light gray sphalerite was not accompanied by high gold values. Shepherd [93] reports a similar situation at the Gunnar Mine in Manitoba where the presence of a dark brown to black variety of sphalerite is indicative of high gold values in the ore. The contrary condition is shown in the Cochenour-Wellans Gold Mine [46] of Quebec where light-colored sphalerite always indicates good values. It is noteworthy that Grout [85a] found that blackjack is much more active than rosin jack in its action on gold chloride solution.

Sphalerite at the Howey Mine,[69] Red Lake, Ontario, is considered a good indication of gold values. This is also true at Thames, New Zealand, according to Morgan.[74] Gold replaces sphalerite in some deposits, for example, in the Black Reef deposits [28] of South Africa and at Goldfield, Nevada,[106] where

myriads of veinlets of gold cut sphalerite. Helke [44] reports relatively large exsolution droplets of gold in sphalerite from the Erzgeberge.

Study of rich gold specimens in the University of Minnesota collection revealed sphalerite as a surprisingly common host or associate of native gold. A particularly rich specimen of coarsely crystalline sphalerite from the Michipicoten district is liberally specked with gold which, on polished surface, appears to have been introduced with galena, both replacing sphalerite (Fig. 6). In other specimens from this area gold is in contact with sphalerite but does not appear to have replaced it.

In rich specimens from the Hollinger Mine gold was found as irregular inclusions in sphalerite which also contained innumerable exsolution inclusions of chalcopyrite and pyrrhotite. The gold inclusions were far too erratic to be attributed to the same process. In another specimen gold grains were clustered with sphalerite, both in quartz (Fig. 9).

Of the 115 districts tabulated in the present study 26 have gold in direct contact with sphalerite. Many other districts have sphalerite in the ore but, as a rule, no statements were made as to the relation of gold and sphalerite. These results agree with those of Lincoln, published in 1911.

Palmer and Bastin found sphalerite a weak precipitant of gold as compared with many of the common sulphides. It ranks about fifth in the number of examples of direct associations which have been described.

Stibnite: Lincoln [66] listed stibnite among the most common minerals with which gold is associated. Out of 585 occurrences of gold in veins 59 contained stibnite and, of these, 28 had a more definite relation with 12 apparently having gold in or on stibnite. Polished surface studies of the past 30 years, however, seem to relegate stibnite to a relatively unimportant position. The writer found no definite descriptions of native gold in stibnite. McCann [71] states that gold is closely associated with stibnite in the Bridge River area of British Columbia but details of the occurrence are not given. Kerr,[59] on the other hand, emphasized

that gold is not directly associated with stibnite in the Whitewater gold belt of the same province.

Palmer and Bastin [80] showed that stibnite was a fairly effective precipitant of gold from chloride solutions, but in the field, examples of this action must be rare.

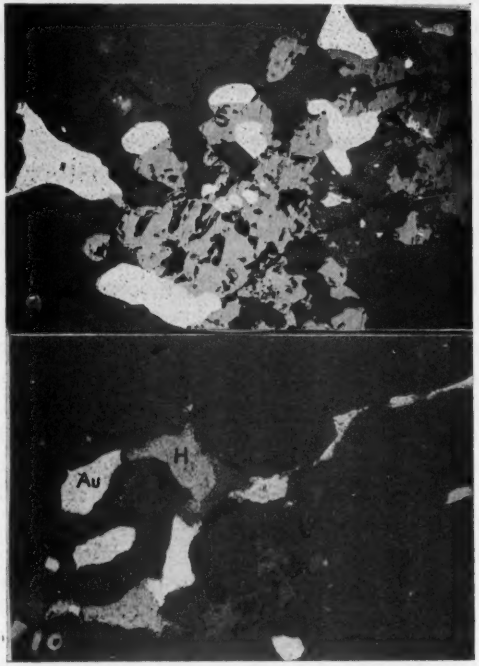

FIG. 9. Irregular gold areas (white) with and included in sphalerite (S) both enclosed in quartz (dark). Hollinger Mine. × 89.

FIG. 10. Gold (Au) and telluride (hessite H) along fractures in quartz. Carson Hill Gold Mine, California. × 170.

Tellurides: The importance of tellurides in some gold deposits is well known. Districts such as Cripple Creek may have most of the gold combined with tellurium. Native gold is also fre-

quently associated with tellurides, whether gold telluride or others. Altaite (PbTe) and tetradymite ($Bi_2(Te, S)_3$) are perhaps the most important of the base metal tellurides associated with native gold. Several examples of ores with tetradymite are referred to under bismuth minerals. The Lake Shore Mine [117] furnished probably the most extensive occurrence of altaite with gold. It is probable that tellurides in gold deposits are almost always accompanied by at least small amounts of native gold. The majority of gold deposits, however, seem to be largely lacking in tellurides and only occasionally are detailed descriptions of the relations available where tellurides are more abundant.

In studies which the writer has made, close association of native gold and tellurides was recognized both in time and in place of introduction (Fig. 10). In rich ore from the Horne Mine, Noranda, Quebec, gold is intimately intergrown with two tellurides (Hessite and altaite), all three apparently contemporaneous.

Tennantite: In a few districts gold occurs in or with tennantite but the latter mineral is not common enough to assume much importance. At the San Mauricio Mine [2] gold is reported to occur in intimate association with tennantite as well as with several other minerals. Mills [72] referred to tennantite in the Iron King Mine as one of the best hosts for gold. In the Yellowknife district of Canada Ridland [86] says that, of the metallic minerals, gold is most commonly associated with tennantite. There are no fractures or other structural controls by the tennantite suggesting a contemporaneous origin.

Palmer and Bastin [80] found tennantite an effective precipitant of gold from chloride solutions.

Tetrahedrite: This important silver-bearing mineral is not common in gold deposits but Jewell [54] reports gold as small irregular grains in tetrahedrite from the Hyder district of Alaska. Stillwell [97] reports gold as minute inclusions in tetrahedrite found in lead concentrates from the Broken Hill Lode, New South Wales. Gold is also reported intimately associated with tetrahedrite and tennantite in the San Mauricio [2] mining district of the Philippine

Islands. Campbell [15] observed gold in tetrahedrite, and in copper carbonates derived from it, in ore of the Bonanza King Mine, Nevada. Gold also occurs with tetrahedrite at Cripple Creek, Colorado. Rounded grains of gold occur in tetrahedrite and also form mutual boundaries in ores from the Skellefte district [79] of Sweden.

Only nine of the deposits reviewed reported gold in association with tetrahedrite or/and tennantite. Lincoln [66] reported a total of 55 gold-bearing veins which carried tetrahedrite, but in only 13 was gold intergrown or disseminated in the tetrahedrite. The conclusion that tetrahedrite is not a particularly favorable host for native gold seems safe.

Uraninite: Gold occurs as part of a veinlet with carbonate in uraninite from Guadalupe,[64] Chihuahua, Mexico.

Other Minerals: Lincoln [66] reported associations of gold with the following metallic minerals in addition to those described above. These minerals were not necessarily in direct contact with gold. The fact that microscopic examination of polished surfaces, largely developed since 1911, fails to report examples of these associations in over 100 deposits suggests that these minerals are of minor importance:

Antimony	Enargite	Stephanite
Arsenic	Cuprite	Miargyrite
Orpiment	Melaconite	Proustite
Realgar	Marcasite	Bornite
Copper	Alabandite	Cinnabar
Covellite	Franklinite	

GANGUE MINERALS.

Amphiboles: The minerals of the amphibole group are not common as vein fillings which, in part, explains their relative unimportance in gold ores. A few occurrences of native gold in amphibole have, however, been described. Frohberg [26] illustrated hornblende crystals embedded in gold from the Michipicoten district of Ontario. Gold occurs along the contact between

sphalerite and actinolite in the Flin Flon Mine [10] of Manitoba. In the Homestake Mine of South Dakota native gold has been found in cummingtonite, but this is a comparatively rare occurrence.

Apatite: In the Kennedy Mine of the Mother Lode district apatite is an important vein mineral. Hulin [50] shows photographs of apatite penetrated and replaced by sulphides and gold. Frohberg [26] shows an apatite crystal almost enclosed in native gold from the Grace Mine, Michipicoten district, Ontario. Apatite is not a common vein mineral in most areas and it could scarcely be expected to be important as a host for gold deposition. Lincoln [66] lists only two gold veins which carried apatite and in neither of these was the association a close one.

Carbonaceous Matter: Various forms of carbonaceous matter occur in some gold deposits and have evidently, at places, played an important role in the deposition of the gold. Rickard [85] long ago described this type of occurrence in the black shale of the Enterprise Mine, Rico, Colorado. He also showed experimentally that gold and silver precipitated on fragments of shale.

Regarding the Rand ores Graton [34] says, "In those mines where it is at all common, the 'carbon' is generally recognized, I believe, as the most significant and reliable of all indicators of good gold values."

Junner [58] considers carbonaceous matter as a favorable host for gold at Ballarat, Bendigo, Clines, and Castelmaine in Australia. At Bendigo carbonaceous matter is definitely looked upon as the precipitating agent.

Wright and Morrell [116] believe disseminated carbon in sheared carbonaceous sediments precipitated gold in the Ymir-Yankee Girl Mine of British Columbia.

Carbonates: Carbonates are frequently important in gold veins; ankerite and allied species are probably more important than calcite. At the Hollinger Mine,[35] for example, much of the visible gold is commonly found in quartz-ankerite zones. It occurs as veinlets along grain boundaries, cleavage planes, twin lamellae and intergrain fractures. Gold also occurs in ankerite

of the Mother Lode area [56] of California, and in the Alaska Juneau Mine [112] gold with ankerite and muscovite occurs along fractures in quartz.

In districts where calcite is present it may be a host for native gold. Frohberg [26] states that native gold in the Michipicoten district is almost invariably associated with a late generation of calcite which occurs as carbonate-feldspar veinlets. Goodspeed [38] noted minute veinlets of gold in calcite from the Cornucopia district of Oregon. Helke [44] illustrates blades and irregular areas of gold in calcite from the Erzgeberge. Gold along the cleavage planes of calcite has been noted at Grass Valley,[56] California, and in southeastern Manitoba.[115] Ransome [84a] states that the veins of the Oatman district consist mainly of quartz, calcite, and adularia with free gold in the ore shoots.

In thin sections of ore from Holquin, Cuba, gold occurs as inclusions in calcite.

In the deposits of the Uchi Lakes area of Canada, Bateman [5] states that in quartz-carbonate veins gold may occur in pyrite and pyrrhotite or even in chalcopyrite, but most commonly as minute grains in carbonate.

Lincoln [66] reported a total of 164 occurrences of carbonates in gold veins out of 585 recorded occurrences of gold in veins. In the majority gold probably did not occur in or on the carbonate but 29 were recorded as gold intergrown, disseminated, or upon carbonates, with calcite by far the most important, but dolomite and ankerite also furnishing examples.

Brokaw's [9] experiments on the secondary precipitation of gold by carbonates showed that all carbonates were active precipitants of gold from chloride solutions.

Chlorite: In the Homestake Mine visible gold is often found in chlorite near vein quartz. From occurrences which the writer has seen it appears that the gold had been precipitated by the chlorite. Perhaps this is the case, since ferrous compounds were shown to be important gold precipitants in experiments by Brokaw.[9] That the precipitation is not simple is, however, suggested by the fact that chlorite does not by any means always act as a selective host for gold.

Pelletier [82] reports that in the Rand ores chlorite in the matrix of conglomerate may contain numerous particles of gold. Price [83] found that some of the gold of the Horne Mine occurs in intensely chloritized rhyolite and metadiabase, in small chloritic areas in massive sulphides, and in quartz areas within rich chloritic gold ores.

In the ores of the Crow River area [102] of Ontario gold is associated with irregularly shaped bodies of pyrrhotite bunched with chlorite along or near fractured zones. Also in the Red Lake area native gold occurs along fractures in quartz where chlorite has been developed. Gold is known in the chloritized and sericitized wall rocks of the Hollinger veins, and at the Lake Shore Mine visible gold occurs along fractures where chlorite has been developed.

In the Waihi Mine,[74] New Zealand, chlorite is considered an indication of payable ore. At Meekatharra,[25] Australia, gold is found largely in chloritic country rock.

There seems some basis for considering chlorite a favorable host mineral for native gold but it apparently is not common enough in most gold ores to receive much notice. Chlorite is an abundant constituent of the greenstones of Canada which are often the wall rocks of Canadian gold veins. Except in the few examples noted above, however, the chlorite has not seemed to localize the values.

Epidote: Lincoln lists a total of 12 gold veins as containing epidote but in only five examples was the information definite and in these the epidote simply occurred in the vein with gold. In the present review of the literature no examples of gold and epidote in contact were found. The writer, however, has observed epidote in contact with, and as an inclusion in, gold in a thin section of ore from God's Lake, Manitoba.

Feldspar: Gold occurs with feldspar in altered country rock but such occurrences do not seem important insofar as visible gold is concerned. Feldspar, particularly albite, is a vein mineral in some deposits of which Hollinger, Mother Lode, and the Michipicoten district come to mind. Frohberg [26] has emphasized

the importance of late albite veins in the vein quartz of the Michipicoten district where the bulk of visible gold is found in or near such veinlets. The writer has observed gold in pink feldspar of ore from the Sylvanite Mine, Kirkland Lake, Ontario.

In epithermal veins adularia is, at places, an important constituent. The writer has been unable to find references to gold occurring in adularia although one can clearly infer that it does from Ransome's description [84a] of the Oatman district, Arizona. In some specimens from this district in the University of Minnesota collections adularia is abundant and a rich specimen shows much gold along the contact of relatively coarse quartz and dense fine-grained adularia. In thin sections the gold occurs as patches of thickly scattered minute grains. The gold seems to favor the adularia but a few grains were observed enclosed in quartz crystals. Examination of other ores containing adularia did not reveal native gold in the adularia although in a thin section of ore from the Mohawk Mine, Fairbanks, Alaska, native gold occurs in a vein near adularia. Both minerals occur in late gold-quartz veins cutting coarse earlier vein quartz. Also in a section of ore from Wall Street, Colorado, gold occurs in quartz of a vein which also contains adularia.

Taken as a whole feldspar seems to play a rather minor role. The writer was inclined to think that the relation of gold to feldspar had been overlooked in the review, but reference to Lincoln's table shows that of 585 occurrences of gold orthoclase was recorded as a vein mineral in only 7 and albite in 10, with a specific contact between feldspar and gold in one ore and a close relation, but not necessarily contact in, twelve examples. Thus, feldspar is not a particularly important host for native gold.

Garnet: Park and Wilson [81] have described the occurrence of gold and garnet at the Battle Branch Gold Mine, Georgia, as follows: "The gold is either angular or leaf-like; it coats garnet and has been seen in small flakes through the garnet and in thin layers between cleavage plates of mica."

Lincoln [66] reported garnet in a total of 13 gold deposits, but in only one was the gold in the garnet; in that case as disseminations.

Kaolin: Some years ago the writer studied a small, high-grade specimen of kaolin gold ore from the San Juan district of Colorado. Extremely finely divided native gold seemed to account for the value. References to kaolin as a gold carrier seem rare in the literature. Dolmage [22] refers to finely disseminated gold in thin films of sericite and kaolin from the Cariboo-Bridge River district. Lincoln [66] reported only four examples of gold in kaolin.

Micas: Sericite is, no doubt, a frequent alteration product in certain gold bearing districts, but only rarely is it specifically mentioned in connection with the occurrence of native gold. Keys [60] states that in the Hollinger vein gold appears to be related to a pale green sericite. They are believed to have been introduced at the same time.

In the Little Long Lac Mine [12] gold is found along sericitic slip planes and in the Cariboo Bridge River area Dolmage [22] noted finely disseminated gold present in large amounts in thin films of sericite and kaolin. Sericite or mariposite are said to be nearly constant associates of gold in the Allegheny district [27] of California.

At the Battle Branch Gold Mine [81] in Georgia gold occurs as thin layers between cleavage plates of mica.

Goddard [32] found small amounts of roscoelite associated with free gold and tellurides in Boulder County, Colorado, and gold has been described in a seam in roscoelite at Cripple Creek. Lincoln [66] reports five examples of gold intergrown with roscoelite.

Probably the less common varieties of mica, such as roscoelite and mariposite, should be considered important as host minerals in a few deposits, but in most deposits gold has little direct relation to mica.

Quartz: The association of native gold with vein quartz is so common and well known that detailed comment seems unnecessary. Some of the unusual features, however, may be referred to and some inferences drawn as to the significance of the relationship. While gold does form contemporaneously with quartz and occurs as small or even large inclusions in it, this is by no means the pre-

vailing relationship. Much more commonly the quartz is earlier and has been fractured, after which gold and often its associated minerals are deposited along the fractures. The literature is filled with references to fracturing of quartz as the important factor in deposition of the native gold. Mawdsley [70] has discussed the problem of late gold at some length. Lincoln [66] found that quartz is always present in gold veins, though not necessarily in appreciable amounts. Occasionally quartz is the important mineral as is emphasized in Gunning's [36] statement on the Cadillac area which follows: "The quartz, however, appears to be of paramount importance and it is probably a fact that where there is no quartz there is no ore." Howe [49] emphasized that at Grass Valley, California, gold occurs in a second period of mineralization in fractured quartz characterized by quartz, calcite, sphalerite, and galena. Barren quartz is unfractured. Johnston states that at Nevada City gold occurs also in sulphide poor quartz, particularly when broken.

In the Boise Basin Hutl [53] says that the vein quartz was fractured by later minor faulting and became a matrix for later mineralization by native gold and lead-bismuth sulphide. In many of the native gold-quartz specimens which the writer has studied under the microscope gold appears along fractures and grain boundaries, often disconnected, it is true, but obviously introduced into the quartz.

Talc: Mawdsley [70] refers to visible gold in green talc found in the Siscoe Mine of Quebec. Lincoln evidently found it of little importance in the older literature as he records it as present in only two deposits.

Tourmaline: In many hypothermal gold deposits tourmaline is present as a vein mineral. It does not, as a rule, seem to have been important in precipitating the gold. In a few deposits, however, gold occurs in contact with tourmaline. Several examples were noted by the writer at the Siscoe and other mines of northwestern Quebec. Gold is generally later than tourmaline and fills fractures in it; for example, a thin section of ore from the McWatters Gold Mine shows a minute network of gold veinlets

in a fine-grained aggregate of tourmaline crystals. Gold also fills fractures in arsenopyrite enclosed by the tourmaline-quartz mass. Similar relations have been reported from the Hollinger Mine to the west in Ontario. Probably the correct view is to regard tourmaline as an important constituent of some hypothermal gold veins but as of relatively little importance as a host for native gold. Lincoln [60] listed a total of sixteen gold veins with tourmaline, but in only 8 was the gold intergrown or with the tourmaline.

Other Minerals: Other non-metallic minerals are known to occur in gold deposits but direct associations of gold with them are evidently rare because the writer found no description of them in the literature of the past 25 years. Lincoln, however, reports in his tabulation that the following occur in gold deposits and, in a few cases, are hosts of native gold: gypsum, fluorite, alunite, pyroxene, serpentine, wollastonite, and rutile.

COMPLEX ORES.

The data reviewed above shows that gold occurs with and in a large number of minerals. The list would include many more minerals if it included all those found in gold ores, but not necessarily hosts for gold. The average gold ore is fairly simple mineralogically but there are occurrences of mineralogically complex ores which are worthy of brief mention.

An outstanding example is furnished by Ridland's [86] description of the mineralogy of the Negus and Con mines of the Yellowknife district. In spite of the fact that metallic minerals are barely visible to the naked eye in this ore, thirty-three minerals were identified, and others in minute amounts were not determined. The important minerals include: gold, tennantite, chalcopyrite, arsenopyrite, sphalerite, gudmundite, nagyagite, sylvanite, chalcostibite, and several lead sulpho-salts. Rare minerals include: galena, altaite, rickardite, siderite, tantalite, pyrrhotite, cobaltite, leucopyrite, stibnite, and other lead sulpho-salts and tellurides. Gold occurs in direct association with quartz, tennantite, arsenopyrite, nagyagite, chalcopyrite, sphalerite, boulangerite, jamesonite, guitermanite, and pyrite.

In some deposits gold is not only found with a number of minerals, but its occurrence may be in various rocks and minerals. The Horne Mine of Noranda, Quebec, furnishes a striking example which has been described by Price.[83] In the summary of gold occurrences the following natural gold associations are recognized: *

1. In pyrite crystals.
2. On the face of pyrite crystals.
3. In magnetite.
4. In pyrrhotite.
5. In chalcopyrite.
6. In intensely chloritized rhyolite and metadiabase.
7. In small chloritic areas in massive sulphides.
8. In quartz areas within rich chloritic gold deposits.
9. In quartz veins in syenite porphyry.
10. In chloritized syenite porphyry.
11. In quartz veins and metadiabase.
12. In later diabase.

SULPHIDES AND GOLD.

The association of gold with the sulphides is a common and important one. Reference in the literature to the close relation of gold and sulphides is frequent even where detailed studies did not reveal which sulphides played the important role. Where the amount of sulphide is small it is fairly evident that the practical point is not which sulphide contains the gold but definite knowledge that it occurs in the sulphides. The writer has examined ores in which the sulphides were disclosed to the naked eye only by dark streaks in the quartz. Examination at high magnifications reveal a number of sulphides with which the high values are associated. Ore has been examined which seems to have only moderate amounts of finely disseminated sulphides in quartz, yet assayed

* A detailed description of polished surfaces of the ore from the Horne Mine may be found in Price's Ph.D. Thesis at McGill University. The writer is indebted to Dr. Price and McGill University for the loan of this excellent description.

900 grams of gold and 17,000 grams of silver per ton. In the treatment of such ores the specific association of the gold and silver values may prove to be of great importance.

Lincoln's compilation, as well as the present summary, serves to emphasize the important role of sulphides in many gold ores. Many workers have recorded opinions and evidence on the significance of this association.

Junner [58] thought that without doubt finely divided pyrite and arsenopyrite caused the precipitation of gold in the veins of Victoria, Australia.

Knaebel [61] stated that at Grass Valley, California, gold is in intimate association with pyrite, galena, and sphalerite, but occasionally free in quartz. No opinion was expressed as to whether or not the sulphides precipitated the gold. Similarly, in the Ouray district, Moehleman [73] emphasizes that though sulphides are in minor amounts compared to quartz they, nevertheless, carry much of the gold. It has been suggested that gold may be dissolved in pyrite or other sulphides and that it has even been in solid solution and then exsolved. Little evidence on these points has been presented but recent, careful microscopic work tends to show that native gold can usually be found in sufficient amounts to explain the values. Warren [111] suggests that the relation of gold to sulphides is mechanical or electro-chemical rather than chemical.

In a very exhaustive study of the occurrence of gold in connection with milling problems the staff of the Lake Shore Mine [117] came to the opinion that there was some genetic relation between gold and sulphides, as vein material carrying sulphides invariably makes ore. However, where native gold is observed in the mine it is usually as isolated specks or blotches within massive quartz or along fractures in quartz where chlorite has been developed.

Even in the much debated Rand ores Pelletier [82] states that half of the gold is locked up in the sulphides.

From relations noted above one might easily jump to the conclusion that gold is so closely related to sulphides that there is some rather definite chemical control but there are notable exceptions also described in the literature. The variation in the

relation of individual sulphides to the gold content has been emphasized in the review of the minerals given above. General statements have also been made; for example, Bradley [8] states that in the Yellow Pine Mine of Idaho gold is apparently enclosed in the early sulphides but no coincident distribution of sulphides is observable. Masses within the vein may be high grade or barren independent of the sulphide present.

Van Aubel [108] also observed in the gold deposits of Kakamega, Kenya Colony, that there was no constant relation between sulphide and the grade of gold. Low gold values are found in high sulphide ore and high gold values in low sulphide.

In describing the Bendigo quartz veins Stillwell [98] refers to gold forming a part of an intimate mechanical mixture with arsenopyrite, galena, pyrite, and sphalerite. Regarding this occurrence Stillwell says, "It (gold) may form a nucleus for crystals of these sulphides, and at the same time be found on the outskirts of the same crystal. This indicates the deposition of all these minerals has occurred together and that one cannot have caused the precipitation of the other." The writer is inclined to apply the same conclusion to the relation of gold to most minerals. The mere occurrence of the gold either in or on a mineral obviously does not necessarily mean that the host had a precipitating effect.

DISCUSSION.

The fairly elaborate summary of data on the relation of native gold to various minerals brings out some points which require brief discussion.

First, it is evident, and has long been recognized, that gold has some preference for certain minerals. It has often been stated or implied that this preference is a result of some sort of selective process of deposition. As noted above this tentative conclusion has been questioned, evidently with increasing frequency in recent years. Granting the selective occurrence it can, of course, be accounted for in more than one way. Aside from selective precipitation two other general factors may be important. One is the time factor, that is, if gold and other minerals are introduced

at about the same time they will naturally occur together without the host mineral of the gold having necessarily had anything to do with precipitating the gold. Late galena and gold furnish an example.

Another factor may be the nature of the mineralizing solution which is capable of carrying and precipitating certain minerals, including gold. Probably not many would argue against the conclusion that pyrite is, in part, an important host mineral for gold because it is of such common occurrence in many types of veins. After all, the bulk of the gold occurs in such common minerals as quartz, carbonates, pyrite, arsenopyrite, galena, sphalerite, chlorite,pyrrhotite, and feldspar.

The structure of minerals has an important bearing on the deposition of gold in minerals as has been emphasized by White in a recent paper in this journal. There is no doubt as to the importance of fracturing in admitting the residual gold-bearing solution to the minerals, quartz particularly, but this explains variation within individual minerals better than variation from mineral to mineral which in some cases may be due to fracturing but in other cases definitely is not.

As a result of a comprehensive review of the literature as well as personal studies, the writer is impressed with the small amount of replacement of the minerals with which gold is associated. Gold does occasionally replace the host minerals but certainly this is the exception rather than the rule as scores of microphotographs showing native gold testify (Figs. 1–10). It is difficult to see how a mineral could act as an effective precipitant unless it entered into the reaction. If it did react then the minerals being precipitated, including gold, should replace the host mineral, unless the precipitation is indirect. Grout [35a] has shown that gold will be precipitated from an acid solution when mingled with an alkaline solution which has dissolved many of the most common sulphides. This may explain the scales of gold which often occur on sulphides which have not necessarily been affected. Warren [109] suggests the possibility of an electrochemical effect which should not be ruled out, but the actuality of the process seems very dif-

ficult to determine. Taking into account the variety of host minerals for gold and the irregularity of the relation in gold ores, the writer is inclined to the conclusion that most host minerals do not act as effective precipitants but are hosts because of a fortunate association in time and place plus a limited precipitating effect, such as is suggested in the above review. The bismuth minerals may be the best precipitants but are not common enough to command much attention except in a few deposits.

It may be worthwhile to comment briefly on the practical aspects of the problem of host minerals of gold. If it could be shown that certain minerals are effective precipitants of gold this fact would be of considerable importance in prospecting and developing gold deposits. Since present data do not prove that certain minerals are effective under varying conditions we are thrown back on more empirical uses of minerals as indicators of gold values. The problem certainly varies from one deposit to another even within a single area and it naturally varies even more from district to district.

As noted above, relatively few minerals carry the values in the majority of deposits. These minerals are thus deserving of special attention. In each case studies should be made to determine by assays and microscopic studies which mineral or minerals carry the values. The minerals which are thus shown to carry the bulk of the values are important not only in exploration and mining, but particularly in milling problems,[117] where some of the less common minerals which may carry gold values are present—for example, bismuth minerals, which warrant particularly careful investigation.

Review of available data leads to the conclusion that more careful study of the relation of gold to specific minerals would be desirable for many deposits.

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MANGANESE DEPOSITS OF THE BROMIDE DISTRICT, OKLAHOMA.[1]

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ABSTRACT.

The Bromide manganese district is in the eastern part of the Arbuckle Mountains of south-central Oklahoma, where folded and faulted lower Paleozoic sediments, chiefly calcareous, are exposed. The manganese deposits are small replacement bodies in the Chimneyhill limestone (Silurian) and are localized very sharply against faults.

The ore consists of several manganiferous carbonates, manganite, hausmannite (?), and minor amounts of manganese silicates, calcite, barite, quartz, pyrite, and hematite—an assemblage very similar to that of Batesville, Arkansas. Carbonates are the most abundant ore minerals in the hypogene deposits, and include manganocalcite, Mn–Ca–Fe–Mg carbonates, calcium rhodochrosite, and manganiferous ankerite. The manganese in the carbonates ranges from less than 5 per cent in manganocalcite and some of the ankerite up to 31.50 per cent in calcium rhodochrosite. The carbonate-manganite ore marketed in the past contained approximately 38 per cent Mn, and the small amount of residual oxide sold has averaged between 40 and 45 per cent Mn.

The manganese minerals are believed to have been deposited from warm, meteoric waters that had leached manganese from the sedimentary rocks of the region. The localization of the ore was controlled chiefly by pre-mineral faults.

INTRODUCTION.

THE six small manganese deposits comprising the Bromide district are located near Bromide in the eastern part of the Arbuckle Mountains. Five of the deposits are in the western third of T. 1 S., R. 8 E., Coal County, 1 to 4 miles north of Bromide. The sixth and largest in the district is about 3 miles southwest of Bromide near the abandoned town of Viola (later known as Springbrook). All of the deposits are connected by improved

[1] Published by permission of the Director, Oklahoma Geological Survey.

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roads with Bromide, where transportation is available on a spur of the Kansas, Oklahoma, and Gulf Railroad.

The deposits have been known for fifty years, and during this time they have been worked intermittently. With the entry of the United States into war there has been renewed prospecting and one operator produced a small amount of manganese oxide in 1941–1942.

The existing explorations together with the geologic information given in this report indicate the deposits are small in size and that the district will never become an important producer of manganese. It may, however, continue to contribute small amounts of 35–40 per cent ore during times of national emergencies.

Previous Work. The general composition of the ore apparently first was recognized by Weeks [3] in 1892, who states: "The (manganese) ore exists in the form of black oxides and carbonates. Both varieties exist together in the same bed, or pockets, averaging say 20 per cent black oxide and 80 per cent carbonate. The deposits apparently lie on the Lower Silurian limestone. . . ." At that time four prospects had been opened in the region north of Bromide.

A brief description of the geology and occurrence of the orebody at the Viola deposit was given by Snider.[4] He believed the ores were deposited along a fault from ground waters that had leached manganese from the sedimentary and igneous rocks of the region.

Hewett, in the company of George Burton of the Oklahoma Geological Survey, made the first comprehensive examination of the deposits.[5] He described the geology and occurrence of the ores and made detailed mineralogical examinations. It was through his work that the unusual nature of the manganiferous carbonates was established and he also was the first to discover

[3] Weeks, J. D.: Manganese. U. S. Geol. Surv. Min. Res. for 1892: 196–198, 1893.

[4] Snider, L. C.: Geography of Oklahoma. Okla. Geol. Surv. Bull. 27: 121–123, 1917.

[5] Hewett, D. F.: Manganese deposits near Bromide, Oklahoma. U. S. Geol. Surv. Bull. 725–E: 311–329, 1921.

hausmannite in the deposits. According to Hewett's interpretation, the manganese minerals were deposited by warm waters rising along fractures.

Merritt [6] re-examined the district in 1941, agreeing with the earlier conclusions.

Present work. The present work includes a detailed field investigation of structure and stratigraphy, with particular emphasis on the structural features that controlled the localization of the ores. Four weeks were spent by the writers in the field making a plane table map (scale 1 inch = 300 feet) with the aid of aerial photographs, examining prospects, and searching favorable localities for new deposits. New contributions resulting from this work include the mapping of several important faults not shown on earlier maps; the recognition that the ore deposits occur exclusively in the Chimneyhill limestone, whereas it previously was thought the deposit at Viola occurred in the Viola limestone; and the recognition that all five, and not just two, of the primary deposits are localized along faults. A mineralogical examination of the ores by Mr. Ham revealed several new minerals, the most important of which are barite, manganiferous ankerite, a comparatively rare calcium rhodochrosite, and neotocite.

Moreover, recent X-ray studies in the laboratory of the United States Geological Survey showed that manganite instead of hausmannite is the most abundant manganese oxide in the deposits.

Development and Production.

The deposits north of Bromide were first worked in 1891, when that part of the State was Indian Territory, and some ore was shipped to Chicago to make spiegeleisen (Table I, Analysis 1). It is reported that development of the Viola deposit began in 1912, but no ore was sold until 1917–1918, when 215 tons containing 32 to 44 per cent manganese was shipped, again to Chicago. Some of the ore in the latter shipments probably came from the deposits north of Bromide. Late in 1940 some more exploration

[6] Merritt, C. A.: Manganese deposits of Oklahoma. Okla. Geol. Surv. Min. Rept. 10, 33 pp., mimeographed, 1941.

work was done, and in 1941–42 an estimated 55 tons of residual manganese oxides was produced. At the time of this writing all the prospects had been abandoned.

Table I shows analyses of ore from the Bromide district.

TABLE I.

ANALYSES OF ORE FROM THE BROMIDE DISTRICT.

	1.	2.	3.	4.	5.	6.
Mn	39.56	37.65	45.75	66.00	66.73	17.71
Fe	6.87	——	12.64	1.23	——	10.78
SiO_2	2.72	6.72	5.29	0.35	0.71	1.60
P	0.057	——	——	0.23	——	0.11
Moisture	4.13	7.34	1.44	——	——	1.08

1. Average of 17 cars (206 short tons) of mixed carbonate-oxide ore shipped in 1891. Cited by Weeks, J. D.: op. cit.
2. Average of five cars (215 short tons) of mixed carbonate-oxide ore shipped in 1917–1918. Private communication from Mr. Robert Galbreath, Tulsa, Oklahoma.
3. Jig concentrates from deposit No. 5 (Lucky 13 mine). Residual oxide. W. H. Howard, analyst. Okla. Geol. Surv. Lab. No. 8885, 1942.
4. High grade residual nodule from deposit No. 5, cited by Weeks, J. D.: op. cit.
5. Selected hausmannite. W. T. Schaller, analyst; cited by Hewett, D. F.: U. S. Geol. Surv. Bull. 725–E, p. 316, 1921.
6. Low grade ore, apparently from deposit No. 3. Cited by Reeds, C. A.: Okla. Geol. Surv. Bull. 3, p. 58, 1910.

GEOLOGY.

The rocks exposed in the Arbuckle Mountains range in age from pre-Cambrian to Lower Cretaceous. The oldest rock—pre-Cambrian granite—is overlain by the upper Cambrian Reagan sandstone and this in turn is followed by a thick succession of Cambrian, Ordovician, Silurian, Devonian, and Mississippian

sediments, chiefly calcareous. In Pennsylvanian time the region was folded and cut by many faults, some of which have been interpreted as overthrusts.[7] The uplifted mountains were reduced to a peneplane and covered by the Lower Cretaceous Trinity sandstone, but most of this sandstone has since been stripped off by erosion. Today the modified peneplane is recognizable as a broad summit "plateau" that is present over much of the region.

Stratigraphy. Although most of the Paleozoic formations of the Arbuckle Mountains are exposed in the vicinity of Bromide, the detailed mapping during this investigation was confined largely to the Chimneyhill limestone which contains the ore deposits. Table II shows the stratigraphy of this bed in the ore district.

One of the most interesting stratigraphic features in the ore district is the pronounced unconformity at the top of the Chimneyhill limestone. At most outcrops little evidence of erosion can be seen, but the unconformity is definitely shown by regional mapping, fossil determinations, and the absence, in this district, of the Henryhouse marl (Niagaran). The Henryhouse marl normally lies between the Chimneyhill and Haragan, and in the western part of the Arbuckle Mountains it reaches a maximum thickness of 81 feet.[8]

Figure 1 is a diagrammatic cross-section based on measured thicknesses in the Bromide district. It shows the southward thinning of the pink crinoidal member of the Chimneyhill in the Hunton anticline area and its absence at Viola. The thinning evidently is caused by a post-Chimneyhill uplift, structurally higher at Viola than near Hunton, and differential erosion of this uplifted surface. The Haragan marl (Zone D_1) also thins to the south in the Hunton anticline and is absent at Viola, but apparently these relations are due to overlapping of the Haragan on the eroded Chimneyhill limestone. In all probability Zone D_1 was not deposited in the vicinity of the Viola deposit.

[7] Dott, R. H.: Overthrusting in Arbuckle Mountains, Oklahoma. A. A. P. G. Bull. 18: 567–602, 1934.

[8] Maxwell, R. A.: The stratigraphy and areal distribution of the "Hunton formation," Oklahoma. Ph.D. dissertation, Northwestern University, 1936.

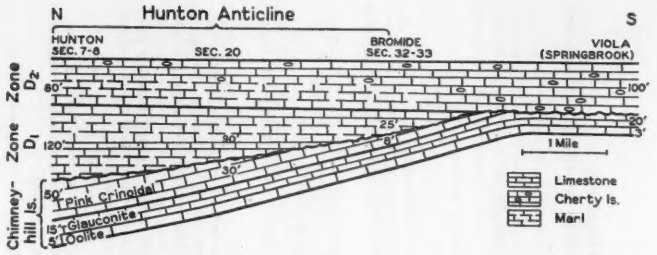


FIG. 1. Stratigraphic cross-section of the Hunton limestone from Hunton to Viola.

The ore deposits are in the Chimneyhill limestone and thus have an apparent relation to the unconformity. Other geologic observations concerning the origin of the deposits, however, indicate that any such genetic association is doubtful. This subject is considered more fully in the section on origin.

Structure. The broader structural features in the Arbuckle Mountains have been mapped by Taff [9] and Decker,[10] and the reader is referred to their articles for general descriptions. In the manganese district the salient structural features, briefly reviewed, are as follows. At the Viola deposit (southwest of Bromide) the ore is related to a major fault and occurs in a bed that is vertical in some places and overturned in others (Fig. 2). The deposits north of Bromide are in the Hunton anticline, the central part of which has been upthrown between two other major faults. The upthrown block, or horst, forms the central part of the anticline and is about 5 miles wide in the region of the deposits. It contains a succession of lower Paleozoic sediments which dip eastward, generally at angles of 2 to 8 degrees (Fig. 3). The formations in the horst are cut by several smaller faults, previously unmapped, that were important in the localization of the ore deposits.

[9] Taff, J. A.: Preliminary report on the geology of the Arbuckle and Wichita Mountains. U. S. Geol. Surv. Prof. Pap. 31, 1904.

[10] Decker, C. E., and Merritt, C. A.: The stratigraphy and physical characteristics of the Simpson group. Okla. Geol. Surv. Bull. 55, 1931.

TABLE II.

STRATIGRAPHY OF THE HUNTON LIMESTONE AND RELATED BEDS NEAR BROMIDE, OKLAHOMA.

System.	Formation.			Thickness (feet)				Lithology.
				Hunton anticline, T. 1 S., R. 8 E.			Viola T. 2 S., R. 7 E.	
				Sec. 7–8.	Sec. 20.	Sec. 32–33.	Sec. 13–14.	
Devonian	Hunton group	Frisco ls.		10	0	0	0	Gray, medium crystalline limestone.
		Bois d'arc ls.	Zone D_3* (ls.)	20			0	Gray, crystalline limestone with abundant chert nodules and thin beds.
		Haragan marl	Zone D_2* (cherty ls.)	80			100	Yellowish, thin-bedded, argillaceous limestone with chert nodules. Important ridge maker.
			Zone D_1* (marl)	120	90	25	0	Buff to yellowish friable marl. A few thin beds of argillaceous limestone.
Silurian		Chimneyhill ls.	Pink crinoidal limestone	50	30	8	0	Pink ls., massive to thin-bedded, containing many fragments of crinoid stems and other fossils. Dense to coarsely crystalline. Chief ore bed in Hunton anticline.
			Glauconitic limestone	15	20	15	20	Gray, medium crystalline, even grained massive limestone. Abundant glauconite and a few chert nodules. Contains ore at Viola and deposit No. 1.
			Oölitic limestone	5	5	5	3	Yellowish to gray massive limestone containing numerous oölites and pisolites. Locally replaced with chert nodules. Contains ore at Viola.

TABLE II.—*Continued*

System.	Formation.	Thickness (feet)				Lithology.
		Hunton anticline, T. 1 S., R. 8 E.			Viola T. 2 S., R. 7 E.	
		Sec. 7–8.	Sec. 20.	Sec. 32–33.	Sec. 13–14.	
Ordovician	Sylvan shale	200		150	125	Green, plastic clay shale.
	Viola ls.; Fernvale phase at top				300	Gray, coarsely crystalline, massive limestone (Fernvale phase) at top; grades downward into cherty limestone.
	Simpson group				950‡	Alternating beds of limestone, sandstone, and shale. Bromide ls. at top.
	Arbuckle group				6,800‡	Dense to coarse-grained dolomite and limestone.
Cambrian	Reagan sandstone				430‡	Sandstone, glauconitic and calcareous.
Pre-Cambrian	Tishomingo granite					Medium- to coarse-grained pink granite.

* Zones D_1, D_2, and D_3 are mappable units in the manganese district, and their recognition is necessary in determining detailed structure. These zones do not correspond to any in the established literature, although they have been given individual names in an unpublished manuscript by R. A. Maxwell: The stratigraphy and areal distribution of the "Hunton formation," Oklahoma. Ph.D. dissertation, Northwestern University, 1936.

‡ Partly or completely absent by faulting; measurements from nearby areas by C. E. Decker: Okla. Geol. Surv. Circ. 22, 1939, and Okla. Geol. Surv. Bull. 55, 1931.

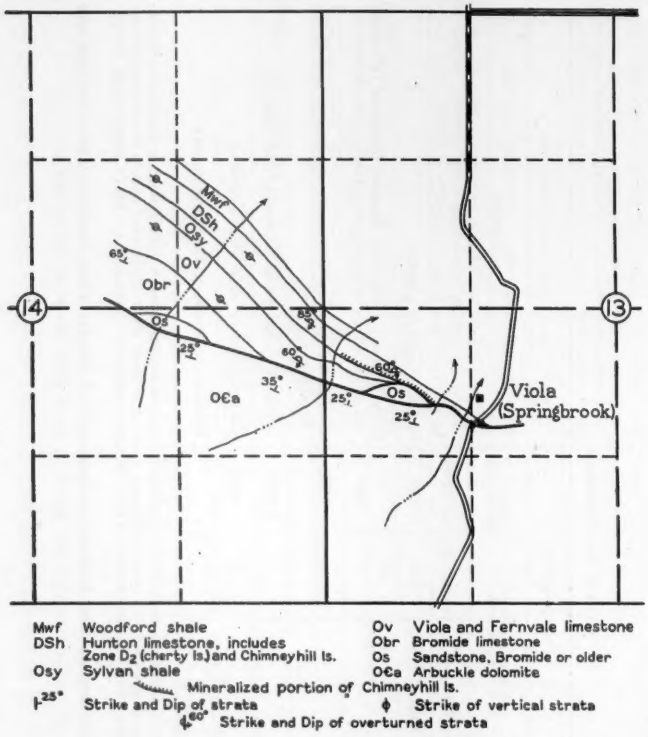


FIG. 2. Geology of the Viola manganese deposit, southwest of Bromide, Oklahoma, T. 2 S., R. 7 E., Johnston County.

ORE DEPOSITS.

Mineralogy. The ores of the Bromide district consist of oxides and carbonates of manganese, together with minor amounts of manganese silicates, iron oxides, quartz, calcite, pyrite, and barite. The most common association is a mixture of dark reddish-brown manganiferous carbonate with granular, black manganite, the whole containing veins and cavity fillings of manganocalcite or pink calcium rhodochrosite (Figs. 4, 5). This type of ore, much

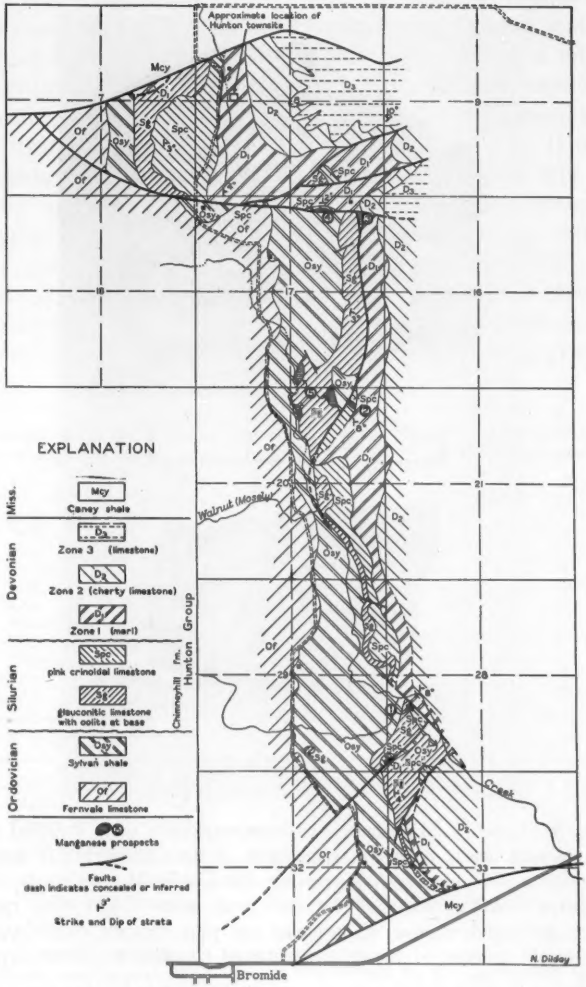


FIG. 3. Geology of manganese deposits in a portion of the Hunton anticline, north of Bromide, Oklahoma, T. 1 S., R. 8 E., Coal County.

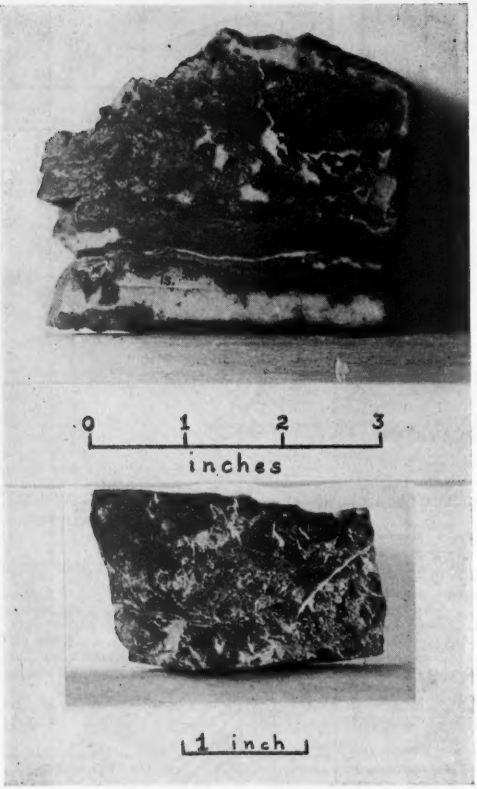


FIG. 4 (Upper). Manganese carbonate-manganite ore. Polished surface showing nearly complete replacement of the Chimneyhill limestone, of which a few pieces (ls.) remain. Mn–Ca–Fe–Mg carbonate with manganite make up most of the dark gray area. Light gray cavity fillings and band at base of specimen are pink calcium rhodochrosite. Microscopic crystals of barite are scattered throughout. From deposit No. 2.

FIG. 5 (Lower). High grade manganite ore. Manganite (black) cut by veins of manganocalcite. Viola deposit.

of it containing 35 per cent or more manganese, is abundant at Viola and deposit No. 1, and constitutes the bulk of material shipped from the district in 1891 and 1918. A second type is composed of yellowish, red, or black manganocalcite, crystalline hematite, and minute grains of hausmannite (?) and generally has less than 20 per cent manganese (analysis 6, Table I). It is the common variety of ore in deposits 2 and 3. A third type is a dense, light gray rock composed of minute rhombohedrons of manganiferous ankerite, with manganese content ranging between 4.97 and 17.71 per cent (analyses 3 and 4, Table III). The above types are of hypogene origin, and derived from them by weathering are residual nodules of high grade ore. Some nodules contain as much as 66 per cent manganese, and consist of granular

TABLE III.

ANALYSES OF MANGANIFEROUS CARBONATES FROM THE BROMIDE DISTRICT, OKLAHOMA.

	1.	2.	3.	4.
CaO	7.86	14.07	29.02	——
MgO	3.99	2.16	14.35	——
FeO	4.11	0.68	4.02	——
Fe_2O_3	4.18	——	——	——
MnO	40.01	40.67	6.42	22.85
CO_2	37.87	39.12	44.89	——
Insol. res.	1.77	4.16	——	——
TOTAL	99.79	100.86	98.70	
Mn	30.98	31.50	4.97	17.71
RECALCULATION				
$CaCO_3$	14.03	25.11	51.82	——
$MgCO_3$	8.35	4.52	30.01	——
$FeCO_3$	6.63	1.10	6.41	——
$MnCO_3$	64.93	65.91	10.40	37.06

1. Dark, reddish-brown manganese carbonate from deposit No. 1; contains disseminated particles of hematite. J. F. Eberle, analyst. Okla. Geol. Surv. Lab. No. 9244, 1943.
2. Pink calcium rhodochrosite from vein, deposit No. 2. J. F. Eberle, analyst. Oklahoma Geol. Surv. Lab. No. 9245, 1943.
3. Dense, gray carbonate from fracture zone, deposit No. 1. Undoubtedly ankerite-rich rock. J. G. Fairchild, analyst. Cited by Hewett, D. F., U. S. Geol. Surv. Bull. 725-E, p. 325, 1921.
4. Gray ankerite from deposit No. 2. Qualitative tests show Ca, Mg, and Fe. J. F. Eberle, analyst.

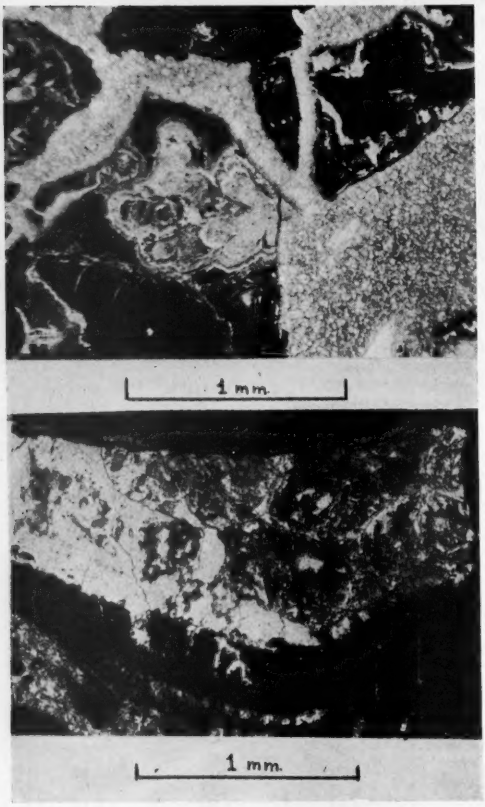


FIG. 6 (Upper). Photomicrograph of manganiferous carbonate-manganite ore. Spherulitic Mn–Ca–Fe–Mg carbonate and manganite (black) cut by veins of granular manganocalcite. Viola deposit. Plain light.

FIG. 7 (Lower). Photomicrograph of carbonate cavity filling. Light gray is coarsely crystalline calcite, about half of which is replaced by fine-grained calcium rhodochrosite. The rock is composed of Mn–Ca–Fe–Mg carbonate and a fine-grained manganese oxide (pyrolusite?). Deposit No. 1. Plain light.

hausmannite and a psilomelane-type mineral. The nodules occur in some quantity at deposit No. 5, where they are associated with clay and chert fragments.

Manganiferous Carbonates. Manganiferous carbonates of several types are the most abundant minerals in deposits 1, 2, 3, and at Viola. Table III shows analyses of some of these carbonates.

Because of its abundance and high manganese content, the most important carbonate economically is the reddish-brown manganese carbonate. Analysis No. 1, Table III, shows it is essentially manganese carbonate with appreciable Ca, Mg, and Fe as isomorphous substitutes for Mn. Typically this carbonate occurs in irregular aggregates of small, anhedral crystals, giving the ore a dense and compact appearance. Here and there, however, it has a spherulitic form, the spherulites having a diameter up to 1 cm. (Fig. 6). In most of the ore at Viola and deposit No. 1 it is intimately associated with black crystalline aggregates of manganite and minute disseminated particles of hematite.

A pale pink, translucent carbonate that occurs in veins and cavity fillings constitutes as much as 10 per cent of the ore in deposits 1 and 2, and occurs sparingly at Viola (Fig. 4). It has a dense to medium-crystalline texture in most occurrences. An analysis (Table III, No. 2) of carefully selected material from a thick vein shows that it is calcium rhodochrosite containing 65.91 per cent $MnCO_3$ and 25.11 per cent $CaCO_3$. The index of refraction ($\omega = 1.763 \pm .003$) checks well with the theoretical value obtained by Krieger [11] for calcium rhodochrosite containing 66 per cent $MnCO_3$. There are other pink carbonates in the district in thin veins that have indices greater than 1.780 and which may approach more closely the composition of true rhodochrosite.

Manganocalcite containing small amounts of manganese occurs in two forms. One consists of coarsely-crystalline anhedral aggregates of yellow, red, or black color that appear to be recrystallized from the original limestone. The color is due in part to included grains of iron or manganese oxides. The aggregates lie

[11] Krieger, Philip: Notes on an X-ray diffraction study of the series calcite-rhodochrosite. Amer. Min. 15: chart facing p. 24, 1930.

chiefly in irregular thin layers parallel to the bedding of the strata in deposits 2 and 3. The second form is fine-grained and granular, has a dull red color, and occurs as veins or cavity fillings in carbonate-manganite ore (Fig. 5, 6).

Ankerite is a common mineral at deposits 1, 2, and at Viola. It has a light gray color and invariably occurs in euhedral rhombohedrons ranging from 0.03 to 0.5 mm. in diameter. The rhombohedrons have a pearly luster where they form drusy coatings on cavity walls, but much of the ankerite occurs as disseminated crystals in the limestone of the deposits, and less commonly in thin veins. With very few exceptions, ankerite does not occur in association with the carbonate-manganite ore and seems to be limited to the outer borders of the mineralized zones. In places it has completely replaced the limestone host rock.

All specimens of ankerite tested chemically contained some manganese, but its composition evidently ranges between rather wide limits. Its composition at Viola and deposit No. 1 is suggested by its index ($\omega = 1.710 \pm .003$). This value is close to an ankerite ($\omega = 1.716$) cited by Larsen and Berman,[12] which contains 52 per cent $CaCO_3$, 26 per cent $MgCO_3$, and 22 per cent $FeCO_3$. Analysis No. 3, Table III, an ankerite-rich phase of deposit No. 1, shows similar percentages of $CaCO_3$ and $MgCO_3$, but with more manganese and less iron. At deposit No. 2 this mineral has a higher index ($\omega > 1.780$) and contains 37.06 per cent $MnCO_3$. (See Analysis 4, Table III.)

Manganite. Until recent X-ray investigations, it had been thought that hausmannite was the most abundant hypogene manganese oxide mineral in the Bromide deposits. The writers are indebted to Mr. Parker D. Trask of the United States Geological Survey who, with Mr. Ham, visited two of the deposits in the winter of 1943. Mr. Trask kindly submitted specimens to the chemical laboratory of the Geological Survey, and Mr. Joseph M. Axelrod made X-ray determinations. Manganite was found in

[12] Larsen, E. S., and Berman, Harry: The microscopic determination of the nonopaque minerals. U. S. Geol. Surv. Bull. 848: 229, 1934.

typical, high grade hypogene ore from the Viola deposit and from deposit No. 1. No hausmannite was found in these two samples.

The mineral identified as manganite occurs in two forms, one of which is not typical of manganite. The non-typical form is in finely granular, massive aggregates and the other is in bundles of slightly divergent, thick fibers. Mr. Michael Fleischer, of the U. S. Geological Survey, advised Mr. Trask that these specimens are the only ones on record from the entire world in which massive manganite is present. Figures 4 and 5 show the massive character of manganite in hand specimen, and Figure 6 shows manganite in thin section. It is to be noted that manganite is associated with the early manganiferous carbonate and was brecciated before the introduction of manganocalcite, calcium rhodochrosite, calcite, and manganiferous ankerite.

Hausmannite. In the recent X-ray study of specimens from Bromide by Mr. Axelrod, hausmannite was found in a sample of the residual nodules from deposit No. 5, but it was not detected in the two samples of hypogene ore from Viola and deposit No. 1. In earlier investigations, chiefly by Hewett, hausmannite was identified by the occurrence of numerous octahedral crystals with perfect cleavage and chestnut-brown streak. An analysis of selected material (Table I, no. 5) showed 66.73 per cent Mn and 0.71 per cent SiO_2. The low content of silica excludes braunite from consideration, and the manganese content is too high for manganite. In the present investigation, furthermore, crystals of octahedral to pseudocubic habit, appearing blood-red in transmitted light, have been observed in thin section (Fig. 8). It is therefore believed that some hausmannite is present in the hypogene ore, even though none has been found in the specimens subjected to X-ray analysis. An additional reason for believing this is the close similarity of the Bromide ores with those from Batesville, Arkansas, in which hausmannite has been identified. As the formation of hausmannite is thought to require rather high temperature, and because the nodules are definitely of supergene origin, it is believed that the hausmannite nodules were derived from hausmannite in nearby hypogene orebodies.

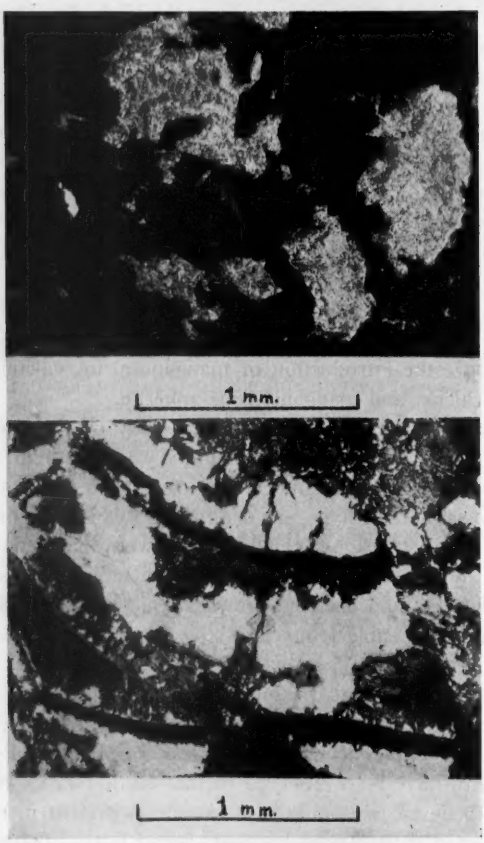


FIG. 8 (Upper). Photomicrograph of hausmannite (?) and rhodochrosite. Pseudocubic hausmannite (?) crystals (black) line old cavities, now filled with calcium rhodochrosite (gray). Deposit No. 1. Plain light.

FIG. 9 (Lower). Photomicrograph of barite, rhodochrosite, and manganiferous ankerite. Barite (light gray) is part of a thick vein in earlier manganese carbonate, not shown in photograph. Calcium rhodochrosite (dark gray) and rhombohedra of manganiferous ankerite, near center, replace barite. Note vein of calcium rhodochrosite cutting ankerite. Black is supergene pyrolusite. Deposit No. 1. Plain light.

In this report the crystals that have octahedral habit and appear blood-red in transmitted light are tentatively classed as hausmannite (?), although possibly it is uncommon in the hypogene ore. Hausmannite (?) occurs chiefly as crystalline encrustations on the borders of masses of manganite, and was deposited before calcium rhodochrosite, calcite, and ankerite. The hausmannite in the residual nodules is in finely crystalline, granular aggregates.

The other manganese oxides in the ores are chiefly of supergene origin. Psilomelane is present as botryoidal encrustations on the manganiferous carbonates and hausmannite, and as loose, residual nodules lying on the surface. Soft, powdery pyrolusite has replaced the carbonate ore in irregular veins and bunches to a depth of a few feet in the deposits. Psilomelane and pyrolusite were the only ore minerals found in the brecciated limestone at deposit No 4.

A few irregular lumps of impure wad were recovered from the clay at deposit No. 5.

Manganese Silicates. Two manganese silicates have recently been recognized in the ores at Viola. Mr. J. A. Straczek of the U. S. Geological Survey identified neotocite during a brief inspection of the area in 1942, and its presence has been confirmed by optical properties and simple chemical tests made by the senior writer. This mineral is deep reddish-brown to nearly black, with a resinous luster, conchoidal fracture, and light brown streak. The specific gravity is 2.95. Simple blowpipe tests show manganese, iron, and silica. Under the microscope it is isotropic, golden brown to yellowish brown in transmitted light, and has an index of refraction of 1.598 ± .003. Both the index and specific gravity are higher than typical neotocite from the Olympic Range, Washington,[13] but the index corresponds reasonably well with that of the neotocite from Gestrickland, Sweden,[14] which ranges up to 1.58. The Gestrickland neotocite contains 24.83 per cent iron oxide and 20.51 MnO. A small amount of weakly birefract-

[13] Pardee, J. T., Larsen, E. S., and Steiger, George: Bementite and neotocite from western Washington, etc. Jour. Wash. Acad. Sci. 11: 25–32, 1921.

[14] Pardee, et al., op. cit.

ing bementite occurs in felted aggregates that evidently have recrystallized from neotocite. Both minerals are distributed sparingly through the orebody in veins and cavity fillings.

Other Minerals.

Calcite, a mineral of late introduction, occurs in thin veins and irregular bunches in ore of all types. It is in coarse crystals up to 2 mm. in diameter and has a white or milky color. It contains only a trace of manganese and its index ($\omega = 1.658 \pm .003$) indicates that it is nearly pure. At deposit No. 3 there are several layers of calcite that contain disseminated aggregates of manganite.

Barite has been found only in deposits 1 and 2, and in neither of them is it abundant. It is present as clear, vitreous, rectangular crystals up to 2 mm. long that line cavities, and as veins in the carbonate-manganite ore (Fig. 9). Locally it fills cavities in which hausmannite (?) crystals had previously been deposited. Some of the veins of barite have been partly replaced by ankerite and cut by veins of pink calcium rhodochrosite (Fig. 9).

Pyrite is distributed sparingly through the deposits in minute crystals and aggregates, and in deposit No. 1 it fills the fissures of the deposit. Generally pyrite is not present in the high grade brown carbonate-manganite ore, but occurs near the outer limits of the orebody. Hewett [15] mentions minute grains of chalcopyrite in the brown manganiferous carbonate in deposit No. 3.

Quartz is a minor constituent in several of the deposits. Clear, vitreous, anhedral quartz fills veins and cavities at Viola; and in deposit No. 1 rounded aggregates of quartz, partly stained with iron oxide, locally replace the limestone. At the latter deposit a few spherulites of chalcedony are present in cavities of the calcite veins. Some cavities in the ankerite-rich rock of deposit No. 2 are partly lined with euhedral quartz crystals up to 2 mm. long, and many are filled with a vitreous, black, brittle asphaltite.

Hematite in minute crystalline aggregates is scattered through the carbonate ore in all the deposits. It is most abundant at Nos.

[15] Op. cit., p. 316.

2 and 3, where irregular stringers and replacement masses, chiefly along bedding planes, are associated with little hausmannite (?) and low-grade manganiferous carbonate. The hematite and its oxidation product, limonite, color the rock various shades of red and yellow.

Paragenesis. Reddish-brown manganese carbonate and manganite appear to be the earliest minerals formed at Viola and deposits 1 and 2. Generally these minerals occur in intimate association as irregular masses in altered limestone, although there are small masses in which only one mineral is present. The two minerals are contemporaneous in most places. The manganite-carbonate period of deposition is the richest in the entire paragenetic sequence, and the value of any deposit is determined chiefly by its content of these minerals.

As manganite is generally considered to be of supergene origin, there might be some question regarding the time of its introduction in the Bromide deposits. In typical high-grade ore, such as that from the Viola deposit (Fig. 5), manganite is embedded in the solid portions of the ore as granular to fibrous, massive aggregates and makes up as much as 50 per cent of the rock. The field relations show that such ore has been emplaced as a part of the hypogene deposit, and the manganite itself does not show textures or structures to indicate that it has replaced earlier manganese minerals. Here and there manganite has an oölitic texture where it has replaced calcareous oölites at the base of the Chimney-hill limestone, but in general it has a characteristic granular texture of its own.

In Fig. 6, a photomicrograph of a thin section of this ore, the textural details of manganiferous carbonates and manganite are shown. The black, massive manganite is intergrown with reddish-brown, spherulitic manganese carbonate, and the intergrowth has clearly been brecciated and invaded by veins of manganocalcite. Other thin sections show veins of calcite and rhodochrosite cutting the carbonate-manganite mixture, and there is good evidence that manganiferous ankerite, neotocite, and barite are also later than the manganite. It seems reasonable to interpret

the manganiferous carbonates, neotocite, and barite as a part of the hypogene mineralization, and if this interpretation is correct, it follows that the earlier manganite is also hypogene.

Hematite also was introduced early into the deposits. It is most abundant in deposits 2 and 3, where veins and irregular replacement masses of hematite are associated with manganite. The few pyrite crystals may belong in time of deposition with the above minerals, but exact relations are questionable.

Following the first mineralization the rock was fractured and brecciated to a minor extent, and a new period of deposition began (Figs. 4–6). Most important of the new minerals were manganocalcite, calcium rhodochrosite, calcite, and manganiferous ankerite. In addition, some veins and cavities contain barite, quartz, neotocite, and asphaltite. The relative amounts of these minerals range between wide limits in the several deposits. Manganocalcite, for example, is the most abundant mineral in deposits 2 and 3, and ankerite is very common at Viola and deposit No. 1. Calcite, rhodochrosite, and the remaining minerals are limited to minor occurrences.

Hausmannite (?), probably uncommon in the hypogene deposits, was apparently the first mineral deposited after the fracturing, as it occurs in granular encrustations on the borders of massive manganite. Calcium rhodochrosite, calcite, and manganocalcite fill the space between hausmannite (?).

From a study of thin sections it is evident that rhodochrosite and ankerite were the last manganese minerals deposited. Veins of dense, pink rhodochrosite replace barite, ankerite, and calcite (Figs. 7, 9); and ankerite replaces veins of barite, calcite, and rhodochrosite. Manganiferous ankerite is abundant as a replacement of limestone on the borders of manganite-carbonate ore; and, because rhodochrosite is lacking on these borders, it is presumed that ankerite was deposited last, thus closing the manganese mineralization.

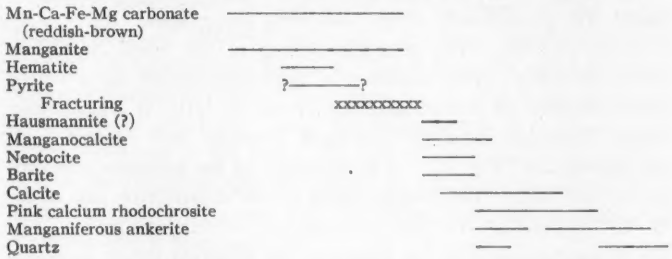
Quartz was deposited in two generations, as shown by its presence in cavities of calcite veins and as euhedral crystals in cavities of ankerite-rich rock. Some of the quartz-lined cavities

contain asphaltite at deposit No. 2, but this mineral may or may not be of hypogene origin.

Supergene minerals in the deposits were formed by surface weathering of the primary or hypogene minerals. They include pyrolusite, psilomelane, wad, hematite, and limonite. All are found from place to place in the oxidized parts of the deposits within a few feet of the surface. Much of the ore recovered to date, however, was rather fresh and contained only small amounts of the supergene oxides.

The paragenetic relations of the hypogene minerals are summarized in the following chart:

PARAGENESIS OF HYPOGENE MINERALS IN THE BROMIDE DISTRICT.



Occurrence and Structural Relations of the Ore Deposits. The previous views concerning the geology of the ore deposits, well summarized by Hewett,[16] include the recognition that the ores are replacement bodies in limestone and that 2 of the 5 hypogene deposits are localized by faulting or fissuring. The structural features which localized some of the deposits in the Hunton anticline were incompletely known.

The detailed field studies by the present writers revealed many new features of structure and stratigraphy, and as a result certain ore relations are now understood more clearly. One important discovery was that all the ore deposits of the district are in the basal part of the Hunton group, that is, in the Chimneyhill limestone (Silurian). This correlation was established after the

[16] Op. cit., p. 317.

Hunton anticline area was mapped in detail, and when it was recognized that the Viola deposit is in the Chimneyhill and not the Viola limestone, as previously thought. Another discovery was that the hypogene deposits are directly related to faulting. Every deposit is associated with a pre-mineral fault or with a fissured zone that branches from one, and the mineralized zones abut sharply against the controlling fault.

The earlier view that the ores are replacement masses is unchanged, for this feature is well exhibited in the form of the deposits, by the local presence in the ore of oölitic and other textures derived from the limestone, and by deeply embayed contacts of manganese minerals with unreplaced limestone.

The form of the deposits and their structural and stratigraphic details are given briefly in the following paragraphs.

Viola Deposit. The geologic setting at the Viola deposit is rather complex. The structure is controlled chiefly by a major fault, possibly an overthrust, that trends N. 70° W., and along which Arbuckle dolomite has been brought into contact with younger strata (Fig. 2). The dolomite on the upthrow side dips 25° to 35° NE. The younger beds on the downthrow side strike N. 45° W. and are vertical to overturned as much as 30°. They are so disposed against the fault that the apparent throw increases to the southeast, and at Viola townsite the throw is at least 1,400 feet. The structure is further complicated along the eastern third of the deposit by a small fault that branches from the major one. Here the lower Chimneyhill, Sylvan shale, and older formations have been faulted out, and the upper part of the Chimneyhill limestone is in contact with a sandstone of the Simpson (Ordovician) group. Northwestward along the strike of the formations the normal stratigraphic succession is present, although the beds are vertical or have been overturned.

The ore is in the Chimneyhill limestone, which is but 23 feet thick at the deposit. Only the oölitic and glauconitic members are present, for all of the pink crinoidal member had been removed before the deposition of zone D_2. The mineralized zone is about 1,000 feet long and 5 feet wide at the outcrop, and consists

dominantly of dense, gray manganiferous-ankerite-rock that contains scattered flakes of glauconite. It has been explored by a series of shallow trenches. In the ankerite rock there are irregular bodies of mixed manganese carbonate-manganite ore which range in size up to one mass reported by Snider [17] that was 50 feet long, 5 feet wide, and 5 feet thick. Manganite-rich bodies of this type were sought for in the exploration development and undoubtedly constituted most of the ore sold from the deposit. The best ore apparently was recovered near the middle and western parts of the deposit, where the Chimneyhill limestone has a normal stratigraphic contact with Sylvan shale. Near the fault only manganiferous ankerite and wad were found.

The mineralization is clearly related in origin to the major fault. The ore solutions evidently circulated within the lower beds of the Chimneyhill limestone along the fault and replaced it with manganese minerals. For some reason that is not apparent, the solutions selectively chose the Chimneyhill in preference to other limestones in the area. There is no manganese mineralization in the Devonian siliceous limestone (D_2), Viola, Fernvale, or Bromide limestones where they touch the fault, and the Arbuckle dolomite also is unmineralized.

The surface dimensions of the deposit are reasonably well defined by the existing trenches to be about 1,000 feet long and up to 8 feet wide. The form of the deposit is tabular and undoubtedly its dip conforms to that of the limestone. There seems to be a good probability that the mineralization continues downward, and the ore reserves, within 100 feet of the surface, have been estimated by Hewett [18] to be 5,000 tons of 35–40 per cent Mn ore. Future development will be somewhat risky because the tenor of the ore depends chiefly upon the percentage of manganite, which has erratic distribution, and mining costs will be high owing to the narrowness and steep dip of the deposit.

Deposits in the Hunton Anticline. The manganese deposits in the Hunton anticline, north of Bromide, are similar to the Viola

[17] Op. cit.

[18] Op. cit., p. 322.

deposit in mineralogy and mode of origin. They differ from the Viola deposit chiefly in the relatively low dip of the host limestone and the smaller size of the controlling faults (Fig. 3). In addition, there is one deposit in the Hunton anticline which contains residual manganese oxide nodules associated with clay, and another in which the ore is psilomelane in brecciated limestone.

Deposit No. 1, in the NW¼ SW¼ Sec. 28, T. 1 S., R. 8 E., most nearly duplicates the conditions at Viola. The outcropping rocks include the three members of the Chimneyhill limestone—oölitic, glauconitic, and pink crinoidal— which dip from 2° to 10° eastward and total about 30 feet in thickness. Near the deposit there are two faults, one trending northwest and the other southwest, that intersect near the center of the SW¼ of Sec. 28. The fault which strikes southwest is about 500 feet south of the deposit and does not seem to have influenced ore deposition. The other fault apparently is genetically associated with the deposit. This fault separates the Chimneyhill limestone from beds in the upper part of zone D_1 and has a throw of about 25 feet.

Branching from the fault, and extending northwestward into the Chimneyhill limestone, is a zone in which there are three parallel, nearly vertical fissures. This zone contains the ore. The mineralized zone has been explored by a trench 75 feet long, 15 feet wide, and 8 feet or less deep which exposes the orebody and extends across the fault into barren marl (Zone D_1). The mineralized zone itself is 20 feet wide and 50 feet long and the base is not exposed in the workings. In the walls of the cut, pink crinoidal and glauconitic limestone have been replaced by gray manganiferous ankerite and small lenses of high grade ore. The masses of high grade ore are 3 feet or more in diameter and consist of an intimate mixture of reddish-brown manganese carbonate with manganite, the whole being cut by veinlets of coarse white calcite and fine-grained, pink calcium rhodochrosite. On either side of the fissured zone the country rock is slightly altered.

In every essential aspect of origin the deposit is similar to the one at Viola, that is, the ore solutions are related to the fault. Unquestionably the deposit is small. Its surface dimensions are

outlined by the fissures and its lower limit is probably fixed by the base of the Chimneyhill limestone, which rests on plastic shale (Sylvan). Considering the low dip and relatively small thickness (30 feet) of the limestone, it is apparent that the deposit will not yield more than a few hundred tons of high grade ore.

Deposit No. 2 is in the NW¼ NE¼ NE¼ Sec. 20, T. 1 S., R. 8 E., about 1½ miles north of deposit No. 1. The most prominent structural feature in this area is a strike fault nearly 2 miles long that cuts through the Chimneyhill limestone. The throw of the fault is greatest, about 60 feet, at the deposit where the top of the Chimneyhill limestone is in contact with Sylvan shale, and on the downthrow side the pink crinoidal limestone and overlying marl of zone D_1 dip 8° E. The glauconitic and oölitic members are faulted out, but total thickness of the formation is estimated from nearby outcrops to be 55 feet (Table II).

The explorations consist of a trench in the pink crinoidal limestone and an open cut in line with the trench. The trench, which trends nearly at right angles to the strike of the fault, is 100 feet long, 20 feet wide, and 5 feet deep; the open cut is 40 feet in diameter and 10 feet deep. The open cut is badly slumped and no bedrock can be seen, but there are good exposures in the trench. Apparently the ore is confined to a narrow zone about 20 feet wide, for on either side of the trench there is unaltered, coarsely crystalline, pink crinoidal limestone. The overlying Devonian marl is unmineralized.

The ore occurs in irregular layers parallel to the bedding of the limestone and consists chiefly of low grade manganocalcite. Here and there are small amounts of hausmannite (?), hematite, barite, and quartz, and in addition there are a few veins of white calcite, pink calcium rhodochrosite, and manganiferous ankerite. A little asphaltite is present in small solution pockets. Much of the rock in the trench and on the dumps is too low in manganese to be of value in normal times.

The narrowness of the zone and its position at right angles to the fault strongly suggest a zone of fracturing related to the fault. The mineralizing solutions evidently migrated up dip (westward)

in the limestone and became ponded against the Sylvan shale at the fault. There appears to be good likelihood that the glauconitic and oölitic limestone members, which have not been explored, are mineralized and may yield marketable ore if manganite or hausmannite (?) is present in abundance.

Deposit No. 3 is in the NE¼ NE¼ Sec. 17, T. 1 S., R. 8 E., 1 mile north of deposit No. 2. The deposit is an irregular lens in the pink crinoidal limestone, which is overlain by Devonian marl and dips 10° E. Exposed in a low escarpment a few hundred feet to the west are the oölitic and glauconitic limestones.

The most prominent structural feature is an east-west fault at the north edge of the deposit. This fault extends northwestward for two miles to the north fault of the horst. At two places along the fault all of the Sylvan shale (200 feet thick) has been faulted out and immediately north of the deposit the marl designated D_1 (120 feet thick) is absent by faulting. A second fault with much smaller throw trends north along the west side of the deposit, where the top of the pink crinoidal limestone is in contact with lower glauconitic limestone. This fault terminates against the east-west fault but continues southward past deposit No. 2.

The deposit has been partly explored by an open cut that follows the dip of the pink crinoidal limestone. The cut is about 125 feet long, 40 feet wide, and 8 feet deep. The orebody is composed chiefly of reddish and yellowish manganiferous carbonates with some manganite and hematite and has a layered appearance. Some of the layers consist of coarsely crystalline white calcite with scattered aggregates of radiating manganite crystals. The ore is very similar in appearance and composition to that in deposit No. 2. An analysis (Table I, Analysis 6) of material from this deposit showed 17.71 per cent Mn, but much of the ore probably contains less.

The intersection of two faults is a favorable place for ore deposition, and undoubtedly the deposit is related to this structural feature.

Deposit No. 4 is about 1,000 feet west of deposit No. 3 and on the north side the same east-west fault. At the deposit the top

few feet of the pink crinoidal limestone and basal beds of Devonian marl are exposed, dipping 2° N. The Sylvan shale is exposed on the south side of the fault which here has a throw of about 100 feet.

Three trenches, each about 20 by 50 feet, a maximum of 10 feet deep, and 75 feet apart, have been cut in the pink crinoidal limestone. Two of the trenches follow the dip of the beds and apparently encountered some ore, although they are now water-filled. The third trench encountered nothing of value. The dumps contain brecciated pink limestone associated with botryoidal psilomelane, the manganese carbonates and manganite characteristic of the other deposits being absent. A composite sample of the dump material contained 31.05 per cent manganese, which indicates that a reasonably good grade of ore could be obtained by hand picking. It is probable that the psilomelane was derived from other manganese minerals which occur in the limestone at depth. The relation of the trenches to the fault and dip of the beds suggests that the ore solutions came from the fault and followed joints or fissures in the limestone.

The supergene oxides resulting from surface weathering of the minerals in the hypogene deposit are for the most part so scattered by running water and ground creep that they can no longer be classed as ore. It is only at deposit No. 5 that residual oxides occur in any quantity.

Deposit No. 5 is made up of three separated patches in the NE¼ Sec. 20 and SE¼ Sec. 17, T. 1 S., R. 8 E. (Fig. 3). In each of the patches black nodules of manganese oxides are distributed through a plastic red clay, and are associated at some places with nodules of manganiferous limonite, irregular lumps of wad, and fragments of chert and undecomposed limestone. The manganese oxide nodules consist dominantly of crystalline hausmannite together with lesser amounts of psilomelane and powdery pyrolusite. Manganese content of the nodules ranges from 45.75 to 66.73 per cent (Table I, Analyses 3 and 5).

The residual material lies on the eroded surface and in widened joint cracks of the glauconitic limestone. The limestone it-

self, however, contains no manganese carbonates or manganite. Most of the ore recovered has come from a system of enlarged joint cracks 1 to 4 feet wide, 8 feet or less deep, and spaced 5 to 10 feet apart. Several attempts have been made to mine the deposit, but it is reported to be too lean and too difficult to work for profitable operation.

The presence of hausmannite in the residual nodules gives a clue to the character of the primary ore, for hausmannite does not form by surface alteration of other manganese minerals and therefore must have come from some hypogene ore body. The absence of manganite, hausmannite, and manganese carbonates in the glauconitic limestone supports the view that these minerals were replacement masses in the pink crinoidal limestone, which formerly overlay the present deposit. Erosion of the pink crinoidal limestone was accompanied by decomposition of the manganese carbonates to form psilomelane, and granular masses of hausmannite, essentially unaltered, were incorporated in the nodules. Together with other weathering products of the limestone, notably clay and chert, the nodules were let down and deposited in solution cracks in the lower limestone members of the Chimneyhill or were scattered over the surface as colluvial debris.

Origin. Significant in the origin of the ores is their intimate relation to the faults of the region. The structural relations clearly show that the ores were introduced as replacement bodies after the faulting incident to the orogeny which deformed the Arbuckle Mountains in Pennsylvanian time. The mineralization is thought to have taken place during the later stages of the orogeny or possibly a short time after it ceased. Certain structural features such as the intersection of faults (Viola, deposit No. 3) and fissured zones adjacent to faults (deposits 1, 2, and 4) were most effective in the localization of the deposits.

The mineral assemblage in the deposits at Bromide, including hausmannite, manganese carbonates and neotocite, is rather rare in comparison to most deposits of manganese ore throughout the world. It is, however, strikingly similar to that in the Batesville district, Arkansas, and in the Olympic Mountains, Washington.

The geologic conditions in the Batesville district led Miser [19] to believe the manganese carbonates and hausmannite were deposited from warm waters of meteoric origin that had leached manganese from the limestone in which the deposits are localized. The bementite-hausmannite ores of Washington are believed by Pardee [20] to have resulted from warm, silica-charged waters acting on limestone containing manganese, probably in the form of carbonate. The source of this water is thought to have been the overlying lavas or their magma. The consensus of opinion is that the hausmannite in these and other deposits has been precipitated from warm or hot waters, and there is no evidence that the Bromide deposits are an exception.

The source of the heat at Bromide is somewhat obscure, for no igneous rocks intruding the Paleozoic sediments are known in the Arbuckle Mountains. Although it is possible that intrusive rocks are present at depth, the writers believe this unlikely, and thus a source of the manganese in hydrothermal solutions of igneous origin seems doubtful. The absence of intrusive igneous rocks and the lack of widespread mineralization in the district strongly suggest that the manganese was derived from local sources, probably by leaching of the sedimentary rocks of the region by warm, meteoric waters. If the meteoric solutions were circulating under artesian pressure at considerable depth, as seems probable, they would be warmer and more effective solvents than surface waters, and thus would be provided the heat that apparently is necessary for the formation of hausmannite. The geographical restriction of the ore deposits to the eastern edge of the Arbuckle Mountains possibly can be explained by a higher original sedimentary content of manganese in the sediments of that area.

The manganese evidently was taken into solution as the soluble bicarbonate and not the sulfate, because sulfates, excepting very

[19] Miser, H. D.: Manganese carbonate in the Batesville district, Arkansas. U. S. Geol. Surv. Bull. 921–A: 42, 1941.

[20] Pardee, J. F.: Manganese-bearing deposits near Lake Crescent and Humptulips, Washington. U. S. Geol. Surv. Bull. 795–A: 13–16, 1927.

small quantities of barite, are characteristically absent in the deposits. The ore minerals are dominantly carbonates and oxides.

It has been noted that the manganese ores in the Bromide district are localized exclusively in the Chimneyhill limestone of Silurian age. This limestone ranges in thickness from 23 feet in the southern part of the district at Viola, to 70 feet in the northern part, near Hunton. There are three distinct lithologic phases: upper (pink crinoidal), middle (glauconitic), and lower (oölitic). One or more of these phases may be mineralized in the same deposit. The deposits are further localized in small areas along faults or their associated fracture zones, the ores grading outward into barren rock within a few feet.

The accumulation of the ore along faults and only in the Chimneyhill limestone might be explained as follows. The Chimneyhill, being more massive and less plastic than the underlying Sylvan shale and overlying Haragan marl, probably has more open joint cracks and other openings than either the marl or shale and would thus serve as a main channel to collect the warm, manganiferous waters. Any fractured zone, such as those along faults, would be even more permeable than other parts of the Chimneyhill. Termination of these fracture zones against faults would result in local ponding of the circulating waters. In addition, the fracture zones may terminate against the fault at a place where the latter is sufficiently open and permeable to allow easy passage of solutions whose composition was different from that in the Chimneyhill. At such places the water from the fault would have the opportunity to mingle with manganiferous solutions in fracture zones of the Chimneyhill, and the resulting locally-formed solution might be such as to cause replacement of the limestone with manganese minerals. It may be assumed that the meteoric waters entered the Chimneyhill at its outcrop and migrated downward, deriving most of the manganese from this bed. An additional amount may have been contributed by waters that percolated slowly downward through overlying formations. In summary, the observed restriction of manganese deposits to the Chimneyhill limestone would be accounted for by its greater permeability than

beds immeditely overlying and underlying it. Localization in fissured zones would be due to their greater permeability compared to other parts of the Chimneyhill. Localization along faults would be accounted for by their damming effect or possibly by mingling of solutions, the solutions contributed by the fault being themselves localized by greater permeability of the fault zone at that place. Absence of deposits along most of the length of the faults would be explained by absence of suitable fissuring in the Chimneyhill or by absence of permeability in the fault zone itself.

The ore minerals were deposited in the crystalline limestone of the Chimneyhill rather than the Sylvan shale or Devonian marl because it was more easily replaced.

There is no apparent reason, however, why the Chimneyhill should be more easily replaced and, therefore, mineralized in preference to other crystalline limestone or dolomite in the district. The Fernvale limestone, Bromide limestone, and Arbuckle dolomite are coarse- to medium-crystalline carbonate rocks and appear amenable to replacement, and at Viola they are near enough to the ore deposit to have been mineralized if the conditions were favorable. The absence of ore in these beds suggests that the circulation of manganiferous solutions was confined principally to the Chimneyhill and probably they did not come into prolonged contact with other beds.

NORMAN, OKLAHOMA,
February 7, 1944.

SIMPLE TESTS FOR THE DETECTION OF THE BERYLLIUM MINERAL HELVITE.

JOHN W. GRUNER.

ABSTRACT.

Helvite from Iron Mountains, New Mexico, occurs as a contact mineral with garnet, fluorite, magnetite, and chlorite. Other minerals may be vesuvianite, hematite, and, of course, calcite. In order to detect easily the helvite and make semiquantitative analyses in the field, a staining method with As_2O_3 or antimony was developed which saved much time and expense.

THE discovery of large amounts of the beryllium silicate helvite at Iron Mountain in the Sierra Cuchilla, Sierra County, New Mexico, was described by Lester W. Strock in this journal in 1941.[1] Jahns has published a note since then on the geology of this deposit.[2] Paleozoic limestone has been intruded by Tertiary aplite and rhyolite masses and caused contact deposits to form. Where the rhyolite invaded the limestone, tactite rock, which resulted, carries scheelite but no helvite. The latter occurs only in tactite where the intrusive is aplite. Helvite occurs in an area about three quarters of a mile long and a few hundred feet wide.

In only one place, locally called "Hot Spot," is it found in considerable concentration. This is the place described by Strock.[1] The gangue minerals are magnetite, garnet-mostly andradite, and some grossularite—, colorless fluorite, greenish black chlorite, and white calcite. The garnet is brownish yellow and can be mistaken for helvite. A brownish vesuvianite is also found, according to Jahns,[2] though more commonly in a beautifully banded rock called "ribbon rock" which occurs in large quantities north of the "Hot Spot." This ribbon rock contains a little helvite.

1 Strock, L. W.: A new helvite locality. A possible beryllium deposit. ECON. GEOL. 36: 748–51, 1941.

2 Jahns, R. H.: The pyrosomatic deposits at Iron Mountain, New Mexico, and their bearing on exploration of beryllium ores. ECON. GEOL. 38: 82, 1943.

The banding is due to diffusion during the replacement of the limestone. Bands of fluorite, chlorite, magnetite, and garnet (and a vesuvianite-like mineral, according to Jahns) alternate to produce a rock of striking appearance. A small amount of finely disseminated hematite gives it a reddish color as a whole.

The helvite has a reddish-brown color and can easily be mistaken for garnet, as it was by the early prospectors. Its crystals closely resemble sphalerite in habit. They may be several millimeters in diameter but commonly are smaller. They have no cleavage. The hardness is about 6 and the specific gravity is 3.32 as determined on handpicked material. This is not very different from that of fluorite, chlorite, and garnet associated with the helvite. The mineral is also magnetic, though a little less than the garnet. Its index of refraction is $1.737 \pm .002$ (measured on crystals from "Hot Spot"). That of the garnet is higher. In studying the material in thin sections one may run across sections in which all of the grains in the field are isotropic though at least three minerals are present.

The structural formula of helvite is $(Mn, Fe, Zn)_4Be_3Si_3O_{12}S$. The Iron Mountain helvite was analyzed by Dr. E. B. Sandell of the University of Minnesota, to whom the writer is indebted for permission to publish the following table:

ANALYSIS OF HELVITE.

SiO_2	32.35
TiO_2	none found
Al_2O_3	0.33
Ga_2O_3	minute trace
BeO	13.75
FeO	16.35
MnO	28.99
ZnO	4.88
CaO	0.23
MgO	none found
S	5.50
H_2O-	0.17
H_2O+	not determined
	102.55
	2.75—less O for S
	99.80

The CaO reported is thought to have been from a little fluorite which is the most difficult impurity to eliminate under the binocu-

lars. The Al_2O_3 probably can be accounted for by substitution of Al for Si and Be, both of which have a coordination of four.

The helvite molecule from Iron Mountain may then be considered to consist of:

$$\begin{pmatrix} 32.7\% & Mn \\ 58.7\% & Fe \\ 8.6\% & Zn \end{pmatrix}_4 Be_3O_{12}S$$

It is, of course, well known that the S in helvite is liberated as H_2S when the mineral is decomposed by acid.

Helvite at Iron Mountain was found in sufficient quantity to warrant some expenditures to see if it could become a commercial source of beryllium. It was soon learned that it would take many elaborate and time consuming chemical analyses to be sure of the tenor of the ore. It was quite impossible to tell by visual inspection alone whether a certain specimen contained enough helvite or any at all. This was chiefly on account of the garnet, vesuvianite, and hematite associations. Many methods were tried at the University of Minnesota, as well as at other institutions and laboratories, to separate helvite from finely ground samples. They were more or less doomed to failure from the start because it was impossible to distinguish helvite from other similar looking grains in the end products. Just to prove the presence of beryllium qualitatively would have been of little value. It was reasoned then that if a method could be found to make the grains of helvite easily visible, either to the naked eye or under the microscope, they could be counted and their ratio to the number of grains of the gangue minerals determined.

Such a method has been developed by the writer and checked by literally hundreds of tests and many chemical analyses. It is quick, simple, and absolutely foolproof. A very small representative sample of the powdered or crushed rock is put in a small 50 cc. glass beaker and enough dilute H_2SO_4 (one acid to five to seven volumes of water) is added to cover the sample. A "pinch" of arsenic trioxide (AS_2O_3) is added, and the solution is boiled for about one to two minutes. The acid is then decanted and

the powder is washed with water a few times by decanting. The contents of the beaker still covered by a little water are examined under the binocular microscope. Any helvite present will be stained a brilliant canary yellow. This stain is arsenic sulphide (As_2S_3) like orpiment. This test is so sensitive that one grain of helvite can be found among thousands of the gangue minerals. Should it happen that the grains were all yellow garnet, the canary yellow could still be spotted. If there were any doubt, *metallic* antimony could be *substituted* for the arsenic trioxide in the test above. A brilliant red would then stain the helvite. This stain is antimony sulphide (Sb_2S_3).

The chemical reaction is, of course, caused by the liberation of the sulphide ion of the mineral on the surface of the grains. This could take place as easily in any other acid, of course, but for reasons not quite understood H_2SO_4 seems to work best. Copper or lead sulphide coatings of dark color can be produced but they are very imperfect and easily peel off. Besides, very dark grains in the powder, for example, magnetite or chlorite, entirely hide the stained grains and obscure the results. In some material, particularly the ribbon rock described by Jahns, much hematitic coloring occurs. In such a case, red antimony sulphide coatings are not easily seen, but the canary yellow As_2S_3 stands out brilliantly. The tests were applied in a field laboratory with great success and saved a great deal of time, labor, and money.

The method was also used on large pieces of ore which had some flat surfaces on them or were polished on one or several sides. It was possible in this manner to locate a few microscopic grains in a large area and show that much material, at first thought to be beryllium ore, was really of little value. Sphalerite gives the same test in hydrochloric acid with As_2O_3 but in H_2SO_4 reacts much more slowly and could be distinguished from helvite. Other sulphides do not interfere.

In conclusion, the writer is indebted to Continental Machines, Inc., Minneapolis, for permission to publish this investigation.

UNIVERSITY OF MINNESOTA,
MINNEAPOLIS, MINN.,
November 23, 1943.

DISCUSSION AND COMMUNICATIONS

DERIVATIVES OF CHROMITE.

Sir: Recently L. E. Sinclair, general manager of the Fantoche mine (Societiete Chimique du Chrome) at Nehoue, New Caledonia, has written to me as follows:[1]

> As judged from a great many samples of serpentine, taken from pretty well all over the island, regardless of proximity to known commercial deposits of either nickel or chromite, it would appear that New Caledonian serpentine, on average, carries 2.5 per cent Cr_2O_3 and 0.3 per cent Ni as essential constituents.

This amplifies the statement at bottom of page 623 and top of page 624 in November 1942 issue of Economic Geology,[2] and suggests that a substantial percentage of leached outcrop material in the New Caledonian serpentine must carry limonitic derivatives of chromite before testing of the ground for commercial oreshoots of that mineral is justified.

ROLAND BLANCHARD.

REPLACEMENT AND IGNEOUS INTRUSION.

Sir: In the March-April number of Economic Geology of the current year, Mr. T. C. Holmes[1] has a paper on porphyry-sedimentary contacts at Porcupine, Ontario. According to Mr. Holmes, in certain cases the sediments adjoining the porphyry, particularly conglomerate, have been changed by magmatic emanations to rocks which can only be distinguished from the porphyry by the shadowy outlines of former pebbles or fragments. The

[1] Personal communication 30/9/43.

[2] Blanchard, Roland: Leached Derivatives of Arsenopyrite and Chromite. ECON. GEOL. 37: 596–626, 1942.

[1] Holmes, T. C.: Some porphyry-sediment contacts at the Dome Mine, Ont. ECON. GEOL., 39: 133–141, 1944.

paper of Mr. Holmes is of particular interest as it corroborates some earlier observations of similar purport.

Dr. Alfred R. Whitman[2] a number of years ago, referring to the same porphyry, adduced considerable evidence to show that its emplacement in many cases was due to processes more suggestive of metasomatic replacement than to those usually associated with intrusive activity. In further corroboration, I may mention that in 1927, near the north shore of Dasserat Lake in the township of the same name in Northwestern Quebec, I saw fine grained pegmatite or granophyre definitely replacing greenstone, an ancient pillow lava of the probable composition of andesite. The granophyre was of a reddish or pinkish color and exactly resembled the mesotasis frequently seen in igneous rocks but was sufficiently coarse grained that the constituent minerals and graphic texture were distinctly visible to the unaided eye. The granophyre replaced the greenstone irregularly along fissures and seams in the latter rock within an area of a few hundred square feet. In one place a cross section of a pillow showed complete replacement. The granophyre did not show a sharp contact against the greenstone but was invariably bordered by a few inches of light colored felsitic material which on the inner side graded into granophyre and on the outer into greenstone.

From the above observations it would seem a reasonable assumption to consider that the whole range of igneous phenomena, from true igneous fusion at one end to hydrothermal activity at the other, when looked at in a broad way, can be regarded as a continuous process without necessarily any definite breaks along its course, and that given favorable circumstances or conditions, a concentrated solution or emanation from the lower part of the hydrothermal zone, heavily charged with rock making constituents, may produce the same results by replacement that is ordinarily ascribed to emplacement by igneous intrusion.

J. A. Reid.

Toronto, Ontario,
April 24, 1944.

[2] Whitman, A. R.: A syntectic porphyry at Porcupine. Jour. Geol., 35: 404–420, 1927.

REVIEWS*

Soil and Plant Analysis. By C. S. PIPER. Pp. xiv + 368; Figs. 19. Interscience Publishers, New York, 1944. Price, $4.50.

The chemists of the Waite Agricultural Research Institute, University of Adelaide in Australia, have been leaders in the science of pedology. The present work is the result of many years of systematic work on Australian soils carried on in the Waite Institute. The author, a chemist at the University of Adelaide, is a foremost soil analyst in Australia.

This volume is considered "a laboratory manual of methods for the examination of soils and the determination of the inorganic constituents of plants." Part I, 244 pages, is devoted to a discussion of methods for soil examination. The topics dealt with include: collection and preparation of soil samples, hydrogen ion concentration, conductivity, soil color, separation and analysis of the clay fraction, exchange capacity, as well as various methods for determination of soil constituents. Part II considers methods for determination of inorganic constituents of plants and includes determination of trace elements.

Soil and Plant Analysis is neatly published in photo offset. It has very few text figures (19) and a minimum of errors of make-up (three of these are corrected). Lists of references to other works have been placed at the ends of most chapters. The author's purpose did not include a discussion of the relation of soil to bedrock, and geologists may criticize this. Nevertheless, the value of this treatise to geochemists and geologists undertaking certain types of research is obvious. The book will be an important addition to many libraries of scientific works.

RALPH E. DIGMAN.

Foreign Maps. By EVERETT C. OLSON AND AGNES WHITMARCH. Pp. xviii + 237; Figs. 25; Pls. 16. Harper and Bros., New York and London, 1944. Price, $4.00.

Carey Croneis, editor of this fifth in Harper's Geoscience Series, introduces the book with the statement "For . . . many reasons which will

* Books noted under *Reviews* and *Books Received* may be ordered through the Economic Geology Bookshop, M. M. Leighton, Urbana, Ill., but orders for official reports and single copies of Journals should be sent directly to their publishers.

be apparent to even the casual reader, it is perhaps not too much to suggest that this volume can, if correctly employed by sufficient persons, make a significant contribution, certainly to the winning of the war, and possibly to the preservation of the peace."

A concise book of 237 pages that still contains all the necessary information, not only simplified for the cartographic novice but collected for the expert from many scattered sources, to enable the reader to locate and use intelligently the maps of any foreign country, is an oasis in a dreary desert of too many words on practically everything. The book is of value not only to those concerned with the present fighting, but to all occupation forces, military and civilian, as well as map-conscious civilians interested in eventual trade, or just interested.

The first chapter summarizes information necessary for correct reading and interpretation of the various maps of the United States and is followed by chapters on Methods in Reading Foreign Maps; Marginal Information; Map Indexes; Problems of Language, including glossaries of terms for 35 languages (from Annamese to Turkish); Languages of Principal Nations and Territories of the World—this chapter includes 16 excellent plates of sample maps of 15 countries; Signs and Symbols; Scales and Measurements; Grid Systems; and Characteristics of Maps of Principal Foreign Mapping Agencies. A good list of references, covering theoretical considerations only briefly touched in the volume, and a very usable index complete the book. Chapter V with the glossaries of terms is probably the most important and useful. These glossaries comprise only map vocabulary and not even a reading knowledge of the language in question is necessary for reading and interpretation of the maps.

This seems to be one book put out hurriedly and under pressure for wartime needs that will prove of real value after the war.

BOOKS RECEIVED.

RALPH E. DIGMAN.

Petroleum and American Foreign Policy. By HERBERT FEIS. Pp. v + 62; Fig. 1. Food Research Institute, Stanford University, Commodity Policy Studies No. 3. Stanford University, March 1944. Price, 50 cents. *Here is a timely and well written article in which the problem of the proposed middle east pipeline is thoroughly discussed. "This study is an attempt to present the pertinent facts and judgments which American policy and action should take into account." The paper is made up of ten chapters and the discussion includes disputes of the past and suggestions toward an agreement, as well as a consideration of the present situation.*

The Diamond Industry in 1943. By SYDNEY H. BALL. Pp. 24; Figs. 3. Jewelers' Circular-Keystone, New York, 1944. *This 19th annual review of the diamond industry is a complete and well-written account on the mining, cutting, distribution and use of diamonds during 1943. The effect of the war on the industry is thoroughly discussed with emphasis on the industry in the United States. Diamond production is discussed by countries and extensive data are given on men employed, value of material removed, profit or loss of companies, as well as production figures. Some mention is made of the geology of most diamond localities.*

U. S. Bureau of Mines. Washington, 1944.

Bull. 449. **Development and Use of Certain Flotation Reagents.** R. S. DEAN AND P. M. AMBROSE. Pp. 89; Figs. 34. Price, 15 cents.

Bull. 453. **Report Submitted to the Trail Smelter Arbitral Tribunal.** R. S. DEAN AND R. E. SWAIN. Pp. 304; Figs. 130. Price, 45 cents. *A report on results of comprehensive studies of atmospheric conditions in the Columbia River Valley near Trail, British Columbia to determine relation between meteorological conditions and discharge of sulfur dioxide from the smelters at Trail.*

Bull. 454. **Fundamentals of Coal Sampling.** B. A. LANDRY. Pp. 127; Figs. 41. Price, 20 cents.

Bull. 455. **Anthracite Mine Fires: Their Behavior and Control.** G. S. SCOTT. Pp. 206; Figs. 82. Price, 40 cents.

Bull. 456. **Coal-Mine Accidents in the U. S.: 1941.** W. W. ADAMS AND L. E. GEYER. Pp. 131. Price, 20 cents.

Bull. 457. **Metal- and Nonmetal-Mine Accidents in the U. S.: 1941.** W. W. ADAMS AND F. J. KENNEDY. Pp. 53. Price, 15 cents.

Tech. Pap. 656. **Analyses of Virginia Coals.** Pp. 159; Figs. 5. Price, 15 cents.

Tech Pap. 657. **Dilution of Stack Effluents.** G. E. MCELROY AND OTHERS. Pp. 46; Figs. 33. Price, 10 cents.

Tech. Pap. 660. **Coke-Oven Accidents in the U. S.: 1942.** W. W. ADAMS AND V. E. WRENN. Pp. 21; Figs. 3. Price, 10 cents.

Tech. Pap. 661. **Electrical Devices Applied to Metallurgical Research.** E. V. POTTER. Pp. 30; Figs. 25. Price, 10 cents.

Tech. Pap. 662. **Thermodynamic Properties of Carbides of Chromium.** K. K. KELLEY AND OTHERS. Pp. 43; Figs. 4. Price, 10 cents.

Miners' Circ. 44. **Construction, Care, and Use of Permissible Flame Safety Lamps.** A. B. HOOKER. Pp. 18; Figs. 5. Price, 10 cents.

Suggested Procedure for Conducting First-Aid and Mine Rescue Contests. G. W. GROVE. Pp. 92; Figs. 14. Price, 15 cents.

Geology and Ore Deposits of the Superior Mining Area, Arizona. M. N. SHORT AND OTHERS. Pp. 159; Pls. 14; Figs. 13. Univ. of Arizona Bull. 4, Vol. XIV., Arizona Bureau of Mines, Geological Series, No. 16, Bull. No. 151. Tucson, 1943. Price, $1.85.

Miocene Foraminifera from Sumatra and Java, Netherlands East Indies. L. W. LEROY. Pp. 113; Pls. 151; Figs. 2. Quarterly of the Colorado School of Mines, Vol. 39, No. 3. Golden, 1944. Price,

$2.00. This paper, in two parts, supplements three papers by the same author dealing with the smaller Tertiary Foraminifera of the Netherlands East Indies which appeared in Vol. 36, No. 1 (Jan. 1941), of the *Quarterly*.

An Annotated Synopsis of Paleozoic Fossil Spores and the Definition of Generic Groups. J. M. SCHOPF, L. R. WILSON, AND R. BENTALL. Pp. 73; Pls. 3; Figs. 5. Illinois Geol. Surv., Rep't of Investigations, No. 91. Urbana, 1944.

Corals from the Chauteau and Related Formations of the Mississippi Valley Region. WM. H. EASTON. Pp. 93; Pls. 17. Illinois Geol. Surv., Rep't of Investigations, No. 97. Urbana, 1944.

The Structural Geology of the Cache Creek Area, Gross Ventre Mountains, Wyoming. VINCENT E. NELSON. Pp. 46; Figs. 17. Augustana Library Publications, No. 18. Rock Island, Illinois, 1942. Price, $1.00.

Coal Resources of the Kansas City Group, Thayer Bed, in Eastern Kansas. WALTER H. SCHOEWE. Pp. 52; Pls. 5; Figs. 8. Kansas Geol. Surv., Bull. 52, Part 3. Lawrence, 1944.

McLouth Gas and Oil Field, Jefferson and Leavenworth Counties, Kansas. WALLACE LEE AND THOMAS PAYNE. Pp. 193; Pls. 10; Figs. 20. Kansas Geol. Surv., Bull. 53. Lawrence, 1944.

Exploration for Oil and Gas in Western Kansas During 1943. WALTER A. VER WIEBE. Pp. 102; Figs. 31. Kansas Geol. Surv., Bull. 54. Lawrence, 1944.

Geology and Ground-water Supply at Camp Van Dorn. G. F. BROWN AND WM. F. GUYTON. Pp. 68. Pls. 13. Mississippi Geol. Surv., Bull. 56. University, 1943.

Monroe County Mineral Resources. F. E. VESTAL AND T. E. McCUTCHEON. Pp. 218; Pls. 5; Figs. 14. Mississippi Geol. Surv., Bull. 57. University, 1943.

Geology and Ground-Water Resources of the Camp Shelby Area. G. F. BROWN. Pp. 72; Pls. 7; Figs. 8. Mississippi Geol. Surv., Bull. 58. University, 1944.

Sillimanite Deposits in the Monadnock Quadrangle, New Hampshire. KATHARINE FOWLER-BILLINGS. Pp. 15; Figs. 9. New Hampshire Planning and Development Commission. Concord, 1944. Price, 10 cents.

Manganiferous Iron-Ore Deposits Near Silver City, New Mexico. L. P. ENTWISTLE. Pp. 72; Pls. 10; Figs. 11. New Mex. Bur. of Mines and Min. Resources, Bull. 19. Socorro, 1944.

Stratigraphy of the Colorado Group, Upper Cretaceous, in Northern New Mexico. C. H. RANKIN. Pp. 26; Figs. 6. New Mex. Bur. of Mines and Min. Resources, Bull. 20. Socorro, 1944.

The Peats of New Jersey and Their Utilization. S. A. WAKSMAN AND OTHERS. Pp. 278; Pls. 15; Figs. 42. New Jersey Dept. of Conservation and Development, Bull. 55, Pt. B. Trenton, 1943.

The Geology and Ground Water Resources of the Emerado Quadrangle. WILSON M. LAIRD. Pp. 35; Pls. 3; Figs. 7. North Dakota Geol. Surv., Bull. 17. Grand Forks, 1944.

Soil, the Most Valuable Mineral Resource, Its Origin, Destruction, and Preservation. W. H. TWENHOFEL. Pp. 45; Figs. 35. Oregon Dept. of Geol. and Min. Indus., Bull. 26. Portland, 1944. Price, 45 cents.

The Natural Resources of South Carolina. Pp. 115; Pls. 24. S. Carolina State Planning Board, Bull. 3. Columbia, 1944.

The "Punch" Jones and Other Appalachian Diamonds. ROY J. HOLDEN. Pp. 32; Figs. 5. Virginia Polytechnic Inst. Bull., Vol. 37, No. 4. Blacksburg, 1944.

Wyoming Vermiculite Deposits. ARTHUR F. HAGNER. Pp. 47; Figs. 10; Pls. 4. Wyoming Geol. Surv., Bull. 34. Laramie, 1944. Price, 50 cents.

SOCIETY OF ECONOMIC GEOLOGISTS

The Council of the Society of Economic Geologists has accepted the cordial invitation of the American Institute of Mining and Metallurgical Engineers to meet jointly with the Institute for such sessions as are of mutual interest. The dates of the technical sessions will be February 19–22, 1945, in the Pennsylvania Hotel, New York City. Members are invited to present papers dealing with any phase of applied geology,—ore deposits, industrial minerals, fuels, ground water, engineering geology, applied geophysics, and mineral economics. Joint sessions will be held with the Mining Geology Committee and with the Industrial Minerals Division of the Institute. Members wishing to present papers should address the office of the Secretary, 411 Schermerhorn Hall, Columbia University, New York 27, N. Y., for the usual abstract forms. No titles will be accepted after December 15, 1944. The Program Committee has been authorized to arrange for a program commensurate with the time available for the sessions and with the best interests of the Society.

Program Committee

H. E. MCKINSTRY, *Chairman*
M. H. GIDEL
JAMES GILLULY
A. I. LEVORSEN
V. T. STRINGFIELD
C. H. BEHRE, JR.

SCIENTIFIC NOTES AND NEWS

DIVISION OF GEOLOGY AND GEOGRAPHY NATIONAL RESEARCH COUNCIL

Report of Activities, May 1943 to May 1944

The annual meeting of the Division was held at the National Academy of Science Building, Washington, D. C., on Saturday, April 29, 1944. The following is a digest of the matters there transacted which are believed to be of special interest to geologists primarly concerned with ore deposits, petroleum, coal, industrial minerals, ground-water, and engineering geology.

The forenoon session opened with brief administrative reports, followed by memorials to Professor E. B. Mathews, formerly State Geologist of Maryland and a charter member of the Society; to Dr. R. C. Wells, widely known among economic geologists for his contributions on the chemistry of ore deposition; and to four other distinguished geologists, Arthur Keith, Douglas Johnson, G. F. Kay, and Frank Leverett. Accredited representatives presented reports on the recent research activities of the cooperating societies. The Geological Society of America reported especially research on the new volcano Paracutin, on radioactivity of oilfield waters, and on progress in assembling the geologic map of South America. The Mineralogical Society report mentioned special work on quartz, of strategic importance. The American Geographical Society announced the completion as of May 1 of a civil division base map of Latin America, as well as a new edition of its Map of Hispanic America, both highly valuable for exploratory and detailed work. The Society of Economic Geologists reported on its work with the War Manpower Questionnaire and on the problems in issuing the Annotated Bibliography and resulting from manpower shortage. The American Association of Petroleum Geologists described the research outlined at its annual meeting and that fostered by the American Petroleum Institute; the effect of radioactivity in breaking down organic compounds was stressed; the Association is also cooperating with the Geological Society of America on the geologic map of South America.

There was extended discussion as to methods for salvaging material accumulated by federal agencies for the conduct of the war; it was pointed out that much material that would be highly valuable in peace times is now being destroyed, while much more will be jettisoned after the war, being regarded as outmoded or only of use in war times. Finally much of the excellent information now available (e.g., on mineral distribution and production) in government bureaus will doubtless be filed away without index and thus become virtually inaccessible. The importance was stressed (1) of saving such materials in the Government Archives and in the Library of Congress and (2) of preparing adequately publicized indexes (at least in such cases in which secrecy is not required for military reasons). Later in the day the creation of a committee to consider this

problem was authorized. Mapping techniques, both geographic and geologic, were discussed. Illustrations of various types of cartography were posted among the exhibits, as were also maps of strategic minerals in various lands. It is clear that the general subject of depiction of data on maps is receiving increasing attention among geologists as well as geographers.

In the afternoon reports were presented by the chairman of the various committees. The Geologic Personnel Committee described the changes by which young geologists were first not recognized as critical to war work and later classed as members of an essential profession; it also discussed the problems of student deferment. Both the Committees on the Glacial Map of North America and on Tectonics reported their maps making progress; that on the glacial geology has reached the engraver and that on the structure of the United States is in the hands of the printer. The Committee of Stratigraphy reported the completion of five of its series of annotated correlation charts. The Committees on Ore Deposition and on the Geology of Ceramic Raw Materials have suspended their activity for the duration of the war. The Committee on Advising Geology Students is making progress, but slowly. The Geography Section, at its separate sessions, gave an account of its detailed census of geographers, which may well serve as a model for a similar census of geologists, such as should be materially aided by the new directory of geologists; the latter has been undertaken by the Geological Society of America with the encouragement of the National Research Council.

CHAS. H. BEHRE, JR.,
Representative
Society of Economic Geologists

N. R. JUNNER of the Geological Survey of the Gold Coast has just been awarded the Lyell Medal of the Geological Society of London.

E. M. SPIEKER has been named chairman of the department of geology at Ohio State University, succeeding J. E. CARMAN who is relinquishing administrative responsibilities to devote full time to teaching. Professor Spieker, on the Ohio State staff since 1924, is on leave until January 1 to work with the U. S. Geological Survey on a survey of strategic minerals in Alaska.

The INSTITUTE OF METALS DIVISION and the IRON AND STEEL DIVISION, A.I.M.E. will hold their regular fall meeting in conjunction with the National Metal Congress at Hotel Statler, Cleveland, Ohio, October 16–18.

HARDEE CHAMBLISS, retired professor of chemistry, and some time dean of the school of engineering, Catholic University of America, has joined the staff of the Geophysical Instrument Co., Arlington, Virginia, as consulting chemist. In the graduate school of the U. S. Department of Agriculture, Dr. Chambliss will give a general introductory course in geochemistry. Geochemical prospecting for oil and minerals will be among the topics discussed. It is said that this is the first course of the kind to be offered in the United States.

V. M. GOLDSCHMIDT of Geologisk Museum, Oslo, Norway, has recently been awarded the Wollaston Medal of the Council of the Geological Society of London.